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MONTHLY WEATHER REVIEW

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(Continued on inside back cover)

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The issue for each month is published as promptly as monthly data can be assembled for preparation of the review of the weather of the month. In order to maintain the schedule with the Public Printer, no proofs will be sent to authors outside of Washington, D. C.

The printing of this publication has been approved by the Director of the Bureau of the Budget, February 9, 1955.

DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, Secretary

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MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

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SILVER DISK PYRHELIOMETRY SIMPLIFIED

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U. S. Weather Bureau, Washington, D. C.

[Manuscript received January 21, 1955]

ABSTRACT

The following devices for simplifying the operation of the Abbot Silver Disk Pyrheliometer are described: (1) an automatic shutter, (2) a simplified heating and cooling timing sequence and (3) an improved method of reading the pyrheliometer thermometer. The authors also describe their experience in automatically recording the silver disk temperature by means of a thermocouple, amplifier, and recorder.

1. INTRODUCTION

The Abbot silver disk pyrheliometer is a device for measuring flux density of the direct solar beam in a plane normal to the sun's direction. Dr. C. G. Abbot, the inventor of the instrument [1], described its principle in 1908 in the following words:

> . . . In a body of measured heat capacity the rate of rise of temperature due to the absorption of radiation is noted and the loss or gain of heat to the surroundings is allowed for by cooling corrections obtained immediately before and after exposure to the sun.

The body in question here is a silver disk, blackened with an efficient absorber of solar radiation and supported in a tube designed to exclude extraneous sky radiation. The time rate of temperature change of the silver disk is determined by reading temperatures at measured time intervals by means of a mercury thermometer, the bulb of which is embedded in the silver disk.

This device is in widespread use over the world. More than 90 of them are used in various countries [2] and in many of these countries provide a basis for the standardization of solar radiation measurements.

Despite this widespread and important use, the instrument is difficult to operate. It places a very considerable burden even on the trained user, and for a beginner to acquire competence in its operation requires extensive practice. It occurred to the authors, who have lately assumed the responsibility of operating this device, that certain modifications could be made which would simplify its operation for them and possibly for others as well. The following is a report of their efforts to this end.

2. CONVENTIONAL PROCEDURE

A description of the procedure followed in conventional operation of the instrument appears in [3]:

> Having adjusted the instrument to point at the sun and opened the cover, read the thermometer exactly at 20 seconds after the beginning of the first minute. Read again after 100 seconds, or at the beginning of the third minute, and immediately after reading, open the shutter to expose to the sun. Note that the instrument is then correctly pointed. After 20 seconds, read again. After 100 seconds more (during which the pointing is corrected frequently), or at the beginning of the fifth minute read again and immediately close the shutter. After 20 seconds read again. After 100 seconds read again, or at the beginning of the seventh minute. Continue the readings in the above order, as long as desired. Readings should be made within ½ second of the prescribed time. Hold the watch directly opposite the degree to be observed, and close to the thermometer. Read the hundredths of degrees first, the degree itself

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afterward . . . A special reading glass is used. It consists of a small eyepiece of about 4 cm. focal length, mounted so that it can easily be held against and moved along the thermometer stem. In the focus exactly in the center of the field is a sharp needle point. By taking readings when the needle point is opposite the top of the mercury column, parallax errors are eliminated . . . Any simple device to beat regular intervals (such as 1, 5, or 10 seconds) permits the observer to concentrate on reading the thermometer instead of trying to read both watch and thermometer at the same time. Such a device also eliminates possible error due to eccentricity of the second hand of the watch . . .

The thermometer-reading program is illustrated in figure 1. As shown, the shutter is open for 2 minutes and closed for 4 minutes.

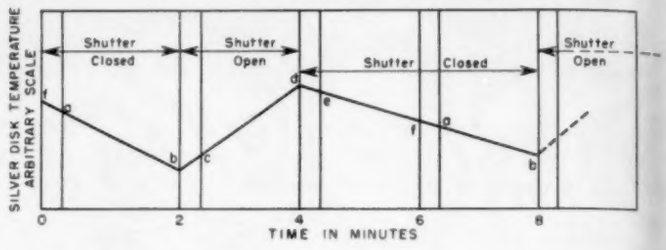
3. SIMPLIFIED PROCEDURE

Simplification of the procedure was aimed at (1) automatic shutter operation, (2) simplification of thermometer reading program, (3) easing of the task of taking thermometer readings.

Automatic Shutter Operation.—Automatic shutter operation was accomplished readily. A rotary type solenoid was employed having a 67½° rotating movement. It was mounted on the barrel of the pyrheliometer and connected directly to the rotating shutter by means of a shaft. The solenoid-driven shutter is opened and closed by means of a synchronous clock switch. Time consumed in shutter movement, as determined by electronic timing equipment, is close to .01 sec.

Simplification of Thermometer Reading Program.—Examination of figure 1 shows that in conventional operation, both the heating and cooling periods are 100 seconds. (The figure represents a typical cycle, say one in the middle of a set of cycles.) The 100-second intervals do not, however, follow each other consecutively. The intervals ab, cd, and ef are separated by 20-second breaks. According to Mr. L. B. Aldrich of the Smithsonian Institution, this 20-second separation was found necessary because the inherent uncertainty in the time required for manually opening and closing the shutter would otherwise introduce errors in the timing of the periods. More reliable observations were obtained by this separation of intervals. The timing sequence is more complicated and more temperature readings are required than would be the case if the 20-second separations could be omitted. After the attachment of the automatic shutter, the 20-second intervals were no longer necessary, hence the time interval sequence or complete cycle for an observation was chosen to consist of three 2-minute periods, one immediately after the other. This sequence results in three fewer temperature readings during a complete observation and a simpler and easier-to-follow timing schedule. Comparisons of results obtained using the old and new timing cycles revealed no significant difference in the calculated flux density for a given period (actually one part in a thousand, in the mean of one set of 9 pairs of readings).

Easing the Task of Reading the Thermometer.—The thermometer on the silver disk pyrheliometer is scaled in the Celsius system, the smallest scale division being 0.1° C. In use, the temperature is estimated to tenths of a division, or .01° C. To facilitate this reading, a low-powered reading glass is held above the mercury column as described in the conventional procedure [3]. The ease of using this glass has been increased by mounting it on a spiral-threaded shaft which is rotated by a crank at the end of the shaft. The shaft is mounted parallel to the thermometer. The pointer of the reading glass can easily be maintained on the end of the mercury column as it rises or falls, by rotating the crank. A buzzer system gives a 10-second warning interval during which the buzzer sounds continuously—at the end of which cranking is stopped. The position of the top of the mercury column as located by the now stationary pointer can be read at leisure, relatively speaking.



Thermometer readings required for one observation:

Conventional procedure: a, b, c, d, e, f. (6 readings required)

Revised procedure: f, b, d, f. (The "f" reading terminating the series is the first reading of the next observation. In a series of "n" observations 3n+1 readings are required.)

Time interval between b and c, d and e, and f and a is 20 seconds.

FIGURE 1.—Shutter program and thermometer reading schedules.

Since the heating and cooling periods are equal, each of a 120-second duration, the timing buzzer is made to sound for the last 10 seconds of each 2-minute period. In practice, by means of a synchronous clock switch, the buzzer is automatically synchronized with the pyrheliometer shutter and also with a large-dial clock equipped with sweep second and minute hands. The minute divisions of the clock, in addition to being numbered, are differentially colored, 2 red and 4 white, consecutively around the dial. The synchronization is so arranged that when the minute hand is over the red markings, the shutter is open, when over the white it is closed. It is thus possible to keep track visually of the progress of the timing sequences. A complete observation starts 2 minutes before the shutter opens and ends 2 minutes after the shutter closes. A glance at the dial at any time during any observation is sufficient to determine just how long it will be before the shutter opens or closes as the case may be.

The use of a motor-driven polar mounting is planned to ease the chore of keeping the pyrheliometer pointed continuously at the sun.

Automatic Temperature Recorder.—When the authors first considered the problem of simplifying the operation of

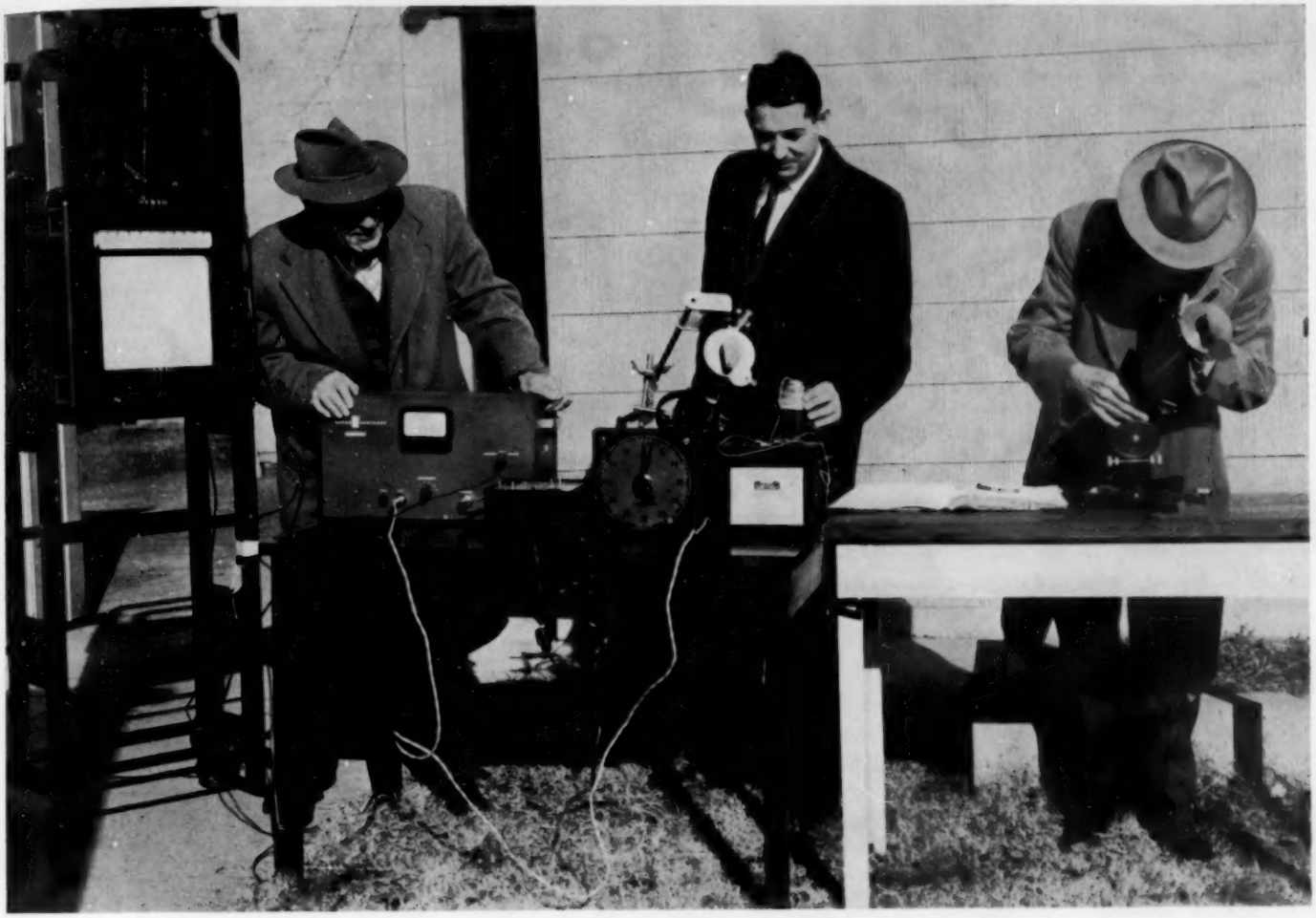


FIGURE 2.—Preparation of normal incidence solar radiation equipment for operation at the Smithsonian Institution. (Left to right, Norman B. Foster, T. H. MacDonald, and L. B. Aldrich.)

the silver disk pyrheliometer they enthusiastically contemplated the use of a thermocouple and recorder for automatically recording the temperature of the silver disk, thus eliminating completely the task of reading the thermometer.

This modification was made and used successfully. After some experience, however, there arose a serious question as to whether the use of automatic temperature recording is a step in the direction of simplification.

The modification consisted of embedding a single-junction copper-constantan thermocouple in the silver disk close to the thermometer bulb. The output of the couple was fed into a breaker-type d-c amplifier and the amplifier in turn fed into a strip-chart potentiometer-recorder. Figure 2 shows the apparatus ready for use.

An analysis of the data obtained with this recording system suggested that the accuracy obtained may have been slightly better on individual observations than those obtained by using the eye-read thermometer. For the average of a set of readings, comprising four or five or more observations, differences between the recorder and conventional results were insignificant. There is some advantage in having the trace as a record which can be checked, whereas the eye-read thermometer reading cannot be checked once made. However, the care in setting up the amplifier-recorder apparatus, in our case out-of-doors, and the necessity for a painstaking calibration of the system, have convinced the authors that the amplifier-recorder system as they employed it presents too many disadvantages to justify its use as a standard procedure.

A complete description and discussion of the amplifier-recorder equipment is given in the Appendix.

4. CONCLUSIONS

Observations with the silver disk pyrheliometer are substantially simplified by the use of auxiliary devices and revised procedures described above. The use of a thermocouple in conjunction with an amplifier-recorder unit for measuring the temperature of the silver disk is believed not to possess sufficient advantage to justify its use as standard procedure.

A statement giving data on calibration of the Weather Bureau silver disk pyrheliometer will be published after more data are obtained.

APPENDIX

A schematic diagram of the equipment used for automatic temperature recording of the silver disk temperature is shown in figure 3. A small hole was drilled in the silver disk and a single-junction copper-constantan thermocouple was embedded in the disk close to the thermometer. A thermos bottle filled with ice and water contained the thermocouple cold junction. The thermocouple was connected to a breaker-type d-c amplifier having an amplifier factor of about 20X. The output of the amplifier was connected to a strip-chart potentiometer-recorder using a paper feed of 4 inches per minute.

If the amplifier-recorder circuit is arranged to record the actual value of temperature on the Celsius scale, then the variations in the temperature—which are the most important element in computation of flux density—are not given in fine enough detail to give the accuracy needed. To overcome this difficulty, the circuits were arranged so that the variations, usually amounting to 2° or 3° C. for any one complete cycle or reading, occupied substantially the complete recorder range. This was done by "elevating the zero" as shown in the circuit schematic.

A voltage sufficient to position the pen near the bottom of the record at the beginning of the observations, when the silver disk is cold, was connected in the circuit by means of a potentiometer in opposition to the voltage generated by the thermocouple. (The corresponding temperature was also read from the silver disk thermometer.) Ideally, a calibrating voltage should be injected into the amplifier immediately before and after the series of observations is made.

Calibration of the Amplifier-Recorder Unit.—Calibration of the amplifier-recorder unit is a vital matter in accuracy control. The circuit used in calibration is shown in figure 3.

A pre-selected current, I, measured by the milliammeter, is sent through the precision resistor R. The voltage drop across the calibrated resistor is then fed to the amplifier and thence to the recorder.

Full scale on the recorder at the recorder input terminals is 6 millivolts.

Corresponding full-scale input to the amplifier, which has a nominal amplification of 20, is close to $6(10^{-3})/20$ or 3×10^{-4} volts.

Resistance of the calibrated resistor R is .01 ohms within $\pm$.02 percent.

Full scale current I through R is then 3×10^{-2} amperes.

Calibration voltage requires that the error be no greater than 0.5×10^{-6} volts. This corresponds to an error of .01° C. in the indicated temperature.

Accuracy of the milliammeter, 0.3 percent; full-scale 10 milliamperes.

Amplification factor "a" is nominally 20.

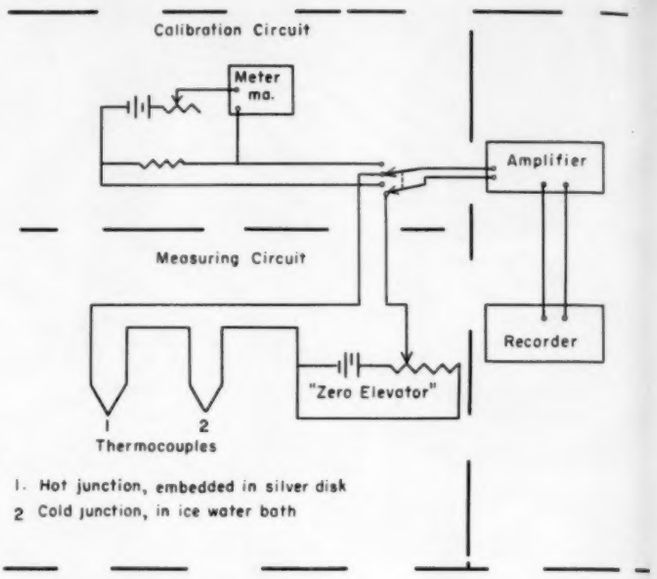


FIGURE 3.—Equipment for automatic recording of silver disk temperature. A more refined apparatus is described in [5].

From $E=IR$ one obtains

$$\Delta E=I\Delta R+R\Delta I$$

Here $R=10^{-2}$ ohms, $\Delta R=2(10^{-6})$ ohms
$I=10^{-2}$ amperes, $\Delta I=3(10^{-5})$ amperes
$\Delta E=10^{-2}[2(10^{-6})]+10^{-2}[3(10^{-5})]=0.32(10^{-6})$ volts
$\simeq$0.3 microvolts

This corresponds to a temperature error of a little less than .01° C.

The calibrating voltage developed by 10 milliamperes across the .01 ohm resistor would give a recorded deflection of about ⅓ of full scale. The reading error of the recorder is about 0.1 percent of full scale corresponding to about ⅓ microvolt. The combination of errors of calibrating voltage (0.3 microvolt) and the reading error (0.3 microvolt) would lead to an error of less than .02° C.

For converting signal to temperature, the authors obtained data on the correspondence of voltage generated by the copper-constantan thermocouple to temperature, to four significant figures, from the National Bureau of Standards [4]. A second-degree equation was computed which fits the data in all cases to the four places given. The data were for 1° C. increments. The parameters in the equation were computed to a sufficient number of places to permit use of the equation in interpolation of the voltages to .01° C. The comparison of results to be described indicates that this procedure did not introduce any systematic error.

Details of Results of Observations.—On September 2, 1954, the weather was favorable for making normal incidence measurements. The equipment was taken to the Smithsonian Institution and set up there for calibration

of our modified normal incidence silver disk pyrheliometer S. I. No. 78 against the Smithsonian APO No. 8 bis.

Three sets of data were obtained. One set was taken using the conventional procedure. The next set was obtained by using the same set of original thermometric readings as in the first case, but omitting readings c, e, and a. The third set was obtained using the amplifier-recorder equipment. Calibration of this unit was done later in the laboratory and not as would be the ideal procedure—immediately before and after the set of observations at the Smithsonian Institution. Nevertheless, results of the calibration give an agreement between the recorder results and mercury thermometer computations within about 0.1 percent.

Because use of the recorder was not contemplated in practice, no further comparisons were made.

ACKNOWLEDGMENT

The authors are indebted to Mr. L. B. Aldrich for making available technical assistance for the installation of the thermocouple in the silver disk pyrheliometer and for supplying solar radiation flux density values for the calibration of the modified equipment.

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2. W. H. Hoover and A. G. Froiland, "Silver Disk Pyrheliometry," *Smithsonian Miscellaneous Collections*, vol. 122, No. 5, 1953.
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4. National Bureau of Standards, "Reference Tables for Thermocouples," *Circular* 508, May 7, 1951.
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CORRECTION

MONTHLY WEATHER REVIEW, vol. 83, No. 1, p. 6: Cuts for figures 9 and 10 are reversed. The one on the right should be figure 9, the one on the left, figure 10.

THE WEATHER AND CIRCULATION OF FEBRUARY 1955[1]

ANOTHER FEBRUARY WITH TWO CONTRASTING REGIMES

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1. THE TWO REGIMES

In four out of five years since this series of monthly articles was started in 1950, it was convenient to discuss the weather and circulation of the first half of February separately from that of the second half [1, 2, 3, 4]. A similar situation prevailed again this February. Figures 1 and 2 show that the mean circulation at 700 mb. was quite different during the two halves of the month, particularly over North America and adjacent oceans. The first half of February 1955 was similar in many ways to the preceding January [5], with a belt of fast westerlies at middle latitudes (fig. 1A), a strong blocking High near Greenland, and an abnormally long half wavelength in the northern United States between a strong ridge along the west coast and a deep trough in the Atlantic (fig. 2A). This pattern produced northwesterly flow and below normal temperatures in much of the country during the first and second weeks of the month (fig. 3A and B).

[1] See Charts I-XV following p. 51 for analyzed climatological data for the month.

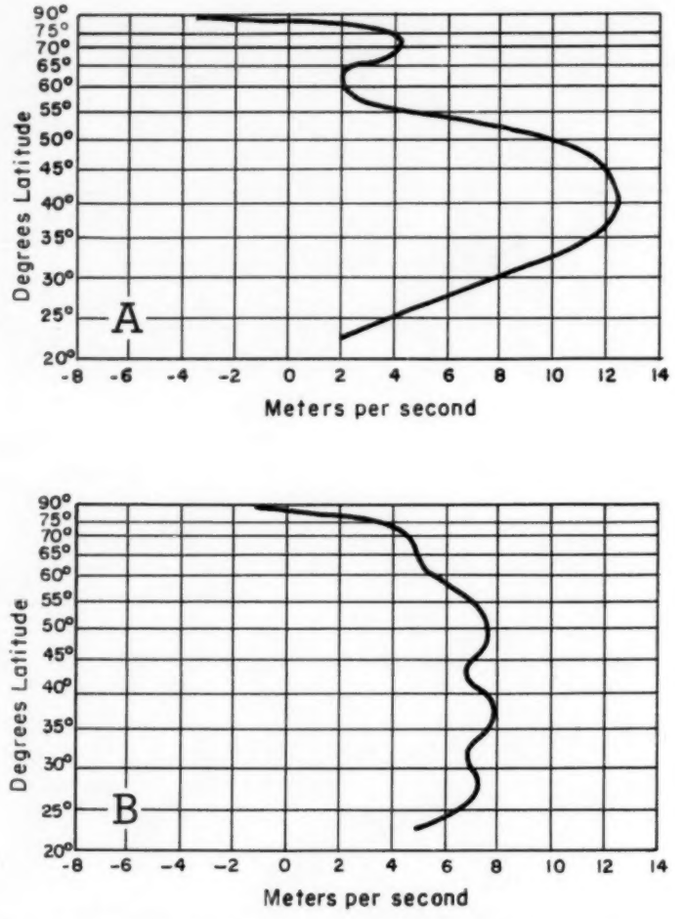

FIGURE 1.—Mean 700-mb. zonal wind speed profiles in the Western Hemisphere for (A) February 1–14, and (B) February 15–28, 1955. Pronounced west wind maximum at 40° N. during first half of month became weak and ill defined during second half of month.

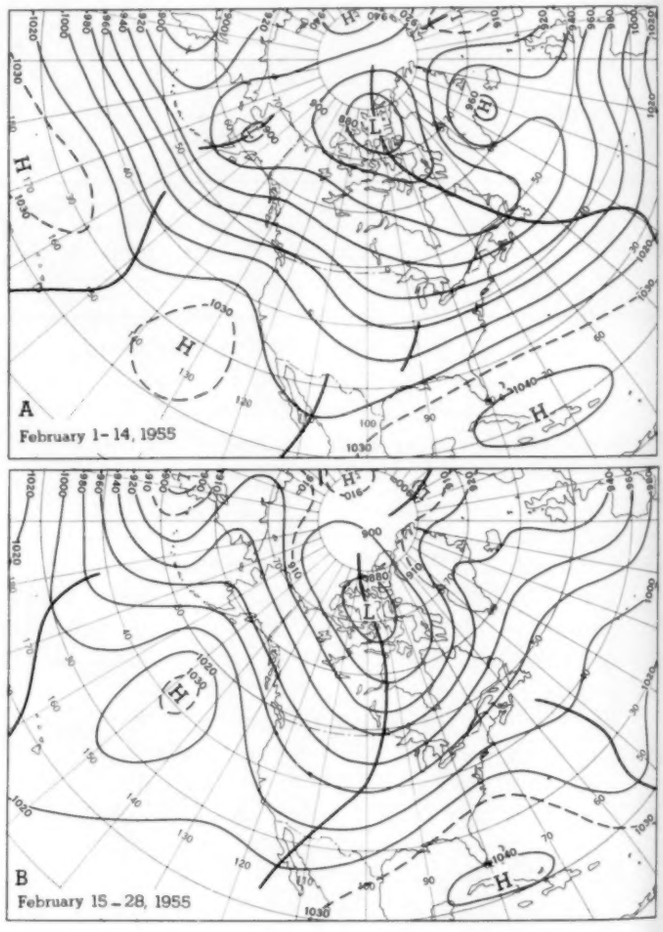

FIGURE 2.—Mean 700-mb. contours (tens of feet) for (A) February 1–14, and (B) February 15–28, 1955. Many features of the pattern retrograded from the first to the second half of the month as amplitudes generally increased and zonal wind speeds decreased.

During the second half of February the mean zonal flow became very weak and ill-defined, and its maximum speed was reduced from 13 to 8 meters per second (fig. 1, compare A and B). This was accompanied by a readjustment of the general circulation at middle latitudes, where wavelengths generally became shorter and amplitudes larger. The trough element which had started to develop in the Mississippi Valley during the first half of the month (fig. 2A) joined with troughs over Lower California and northern Canada to form a single full-latitude trough which dominated the entire North American circulation during the second half of February (fig. 2B). At the same time, the amplitude of adjoining ridges increased greatly, particularly in the eastern Pacific. Between the Pacific ridge and the North American trough strong northerly flow produced below normal temperatures in the western half of the United States (fig. 3C and D). The last week of February was the coldest week of the winter in the Northern Plains, where temperatures averaged 15° to 18° below normal over a wide area which had averaged above normal all winter long [5]. In the eastern half of the United States, on the other hand, strong southwesterly flow ahead of the newly developed trough resulted in the warmest weather of the winter during the last two weeks of February, with extreme departures of +12° in northern New England (fig. 3D). In the Atlantic the closed blocking High which had been over Greenland merged with the subtropical ridge, while the deep trough in mid-ocean sheared off from its Canadian affiliate and filled considerably at middle latitudes.

The contrast between the circulation patterns of the first and second halves of the month is highlighted in figure 4, which shows the departure from the February normal of the mean 700-mb. heights given in figure 2. During the first half of the month the largest hemispheric anomaly, +610 ft., was found in the blocking High over Greenland. In the United States heights averaged somewhat above normal, but departures were generally small and anomaly gradients weak.

The largest 700-mb. height anomaly in the Northern Hemisphere during the second half of February was found in the northeastern Pacific, with extreme departure of +740 ft. centered at 50° N., 154° W. (fig. 4B), northwest of the High center at 700 mb. (fig. 2B). In this area mean heights rose over 600 ft. from the first to the second half of the month. Large positive anomalies in this portion of the Pacific are frequently accompanied by above normal heights in the eastern United States. For example, a correlation of +0.57 has been noted between simultaneous anomalies of wintertime monthly mean 700-mb.

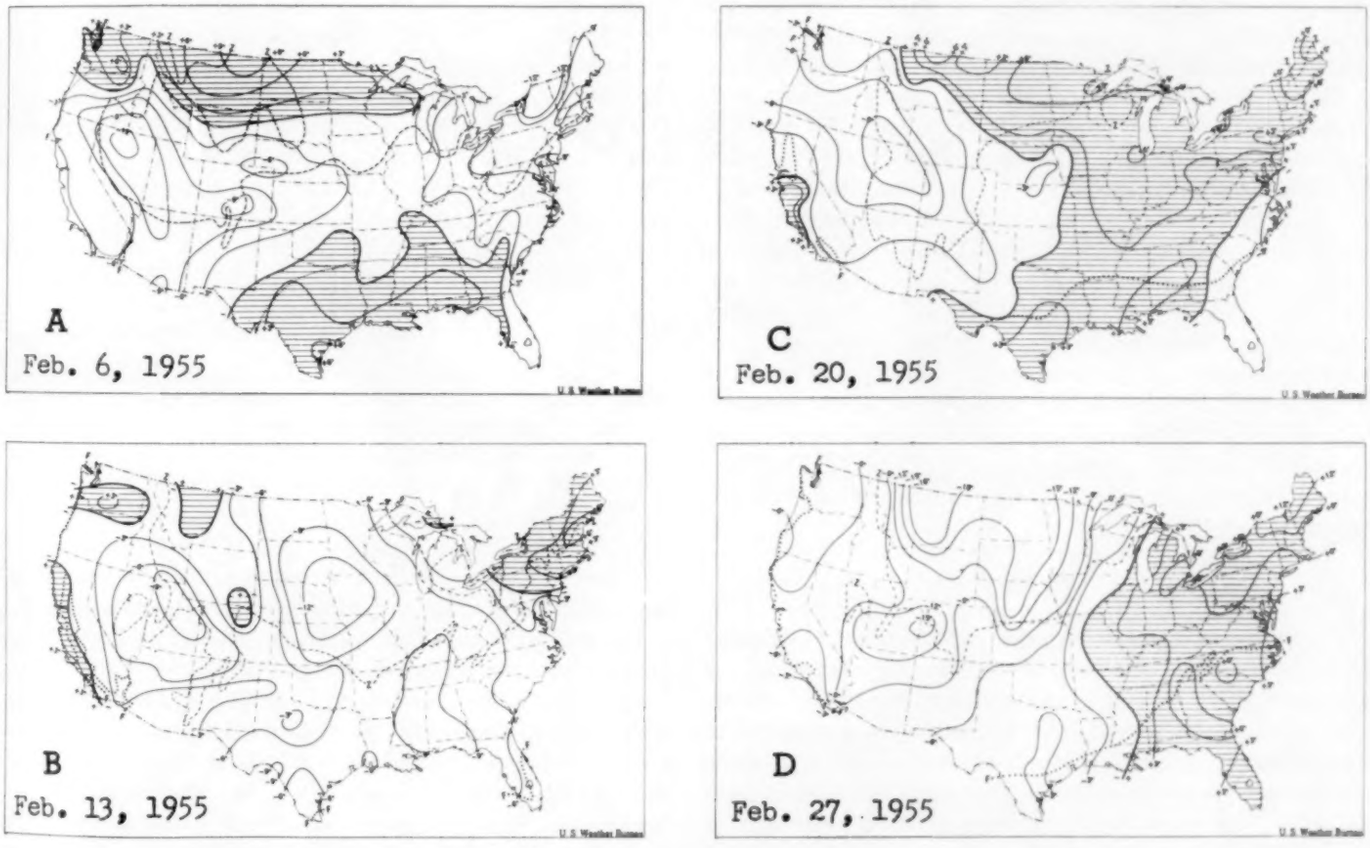

FIGURE 3.—Departure of average temperature from normal (° F.) for the weeks ending at midnight, local time, on the dates shown. Shading indicates temperatures of normal or above; dotted line shows southern limit of freezing temperatures; dashed line southern limit of zero degrees. Note trend toward warming in East and cooling in Northern Plains. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. 42, Nos. 6, 7, 8, and 9.)

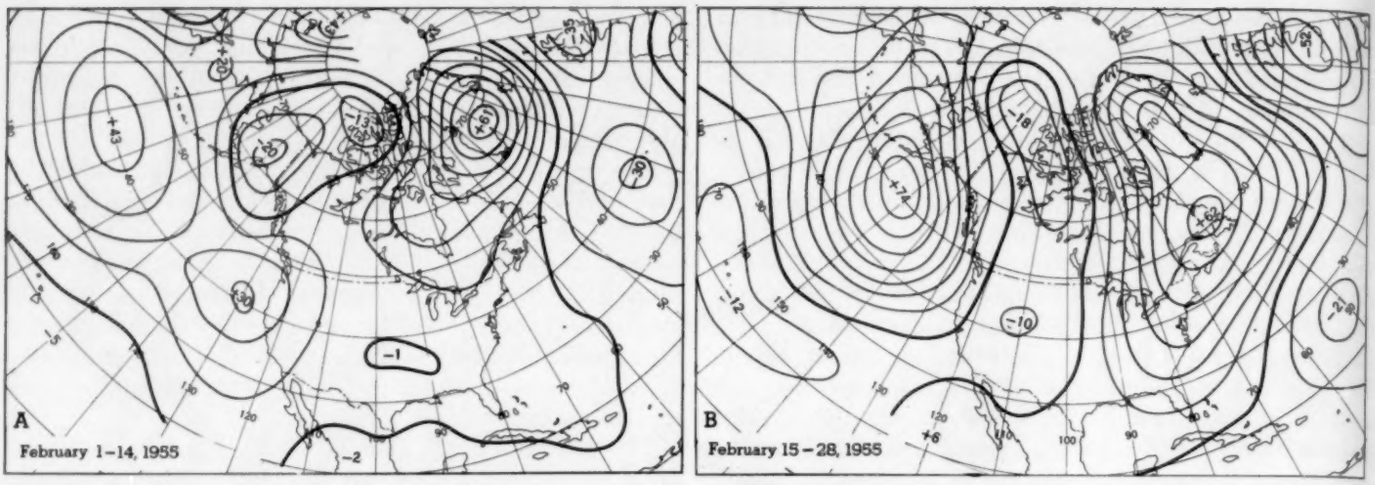

FIGURE 4.—Departure from normal of mean 700-mb. heights shown in figure 2. Isopleths are drawn for intervals of 100 ft. with zero line heavier and anomaly centers labeled in tens of feet. First half of month was dominated by strong positive anomaly of blocking type over Greenland. Development of strong positive anomaly in northeastern Pacific during second half of month was accompanied by marked falls in height in western half of United States and rises in eastern half.

height at 40° N., 150° W., and 35° N., 75° W. [6]. Even more striking is the marked similarity in pattern between the lines of equal height anomaly in figure 4B and the lines of equal percentage frequency in figure 5, taken from an extensive study of circulation teleconnections by Martin [7]. This figure shows how often 5-day mean 700-mb. heights during the winter months were above or below normal when any axis of maximum anomaly was located at 50° N. between 150° and 160° W., the very area with largest positive height departure in figure 4B. Positive anomalies in this area were accompanied by negative height anomalies in the Great Basin on 90 percent of 5-day mean maps during past winters, while heights were above normal along the east coast 70 percent of the time during the same period. It is not surprising, therefore, that during the second half of February 700-mb. heights increased markedly to well above normal levels throughout the eastern half of the United States, but fell sharply to below normal values in the western half of the country. From this point of view the circulation anomalies observed over North America during the second half of February may be considered to be a resonance effect of corresponding anomalies in the Pacific.

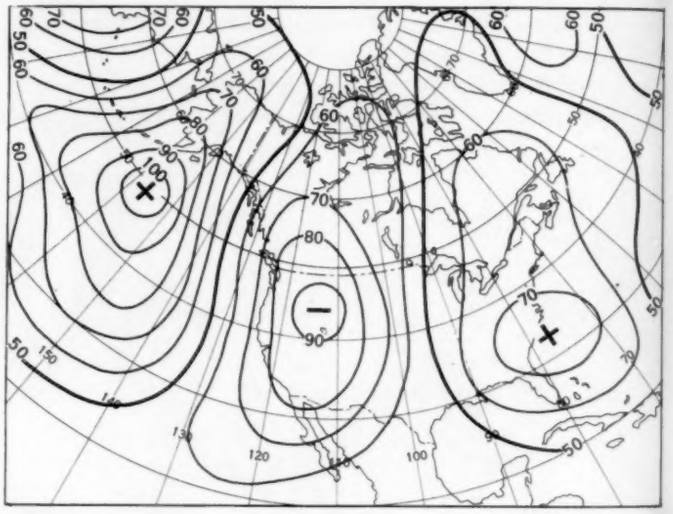

FIGURE 5.—Percentage frequency of sign of 5-day mean 700-mb. height anomaly for all wintertime cases from 1946 to 1952 when an axis of maximum anomaly at 50° N. lay within the area from 150° to 160° W. (from [7]). Isopleths are drawn at intervals of 10 percent with 50 percent line heavier. Note striking similarity to figure 4B.

2. THE INDEX CYCLE

The non-homogeneous nature of February circulation during five of the past six years may be related to the fact that the primary index cycle of the year usually occurs in that month [6]. The index cycle is a period of several weeks during which the strength of the zonal westerlies at middle latitudes gradually declines from comparatively high to low values and then recovers. A particularly pronounced cycle of this sort was associated by Winston with a large-scale change in circulation during February 1952 [3]. An equally pronounced index cycle accompanied this February's change in weather regime.

Figure 6 depicts the time variation of 5-day mean values of the 700-mb. zonal index computed twice weekly from average heights at latitudes 35° and 55° N. in the Western Hemisphere from mid-November 1954 to mid-March 1955. The index cycle may be considered to begin at the high point of the graph, denoted by the arrow, a value of 13.8 m./sec. observed during the 5-day period centered January 31, 1955. This was 2.8 m./sec. above normal and the highest value observed during any 5-day period since December 11, 1953. For the next 3 weeks the index declined irregularly, reaching values 4 m./sec. below normal in the periods centered February 18 and 21. The minimum of 5.9 m./sec. on the 18th was the lowest index

TABLE 1.—*Monthly mean values of the 700-mb. zonal index (35°–55° N.) in the Western Hemisphere (all units in meters per second)*

Month	Observed index	Normal	Anomaly
December 1954	10.5	11.3	−0.8
January 1955	10.5	11.8	−1.3
February 1955	9.2	10.2	−1.0

observed during any 5-day mean period since July 1954 and the lowest in any winter period since February 1952. Thereafter the index rose in irregular fashion to above normal values during the second week of March, and the index cycle was terminated.

In its overall aspects this year's index cycle was quite typical of the type described by Namias [6]. However, it was somewhat unusual in three respects. In the first place the low point of the cycle, on February 18, was reached about two weeks earlier than the average date of occurrence. Secondly, the falling index stage of the cycle was not accompanied by expansion of the circumpolar vortex in the classical fashion; in fact, the subtropical (20°–35° N.) westerlies were weaker than normal and the polar (55°–70° N.) westerlies stronger than normal at 700 mb. during most of February. Finally, this year's index cycle was preceded by two minor cycles with low points reached on December 20 and January 7 (fig. 6). Although neither of those cycles was as prolonged or intense as the primary cycle of February, they were sufficient to produce below normal monthly mean values of the zonal index at 700 mb. during both December and January (table 1). Since the February value was also below normal, this winter was the first in our records (starting 1943) to have below normal values of the 700-mb. zonal index during all three months of the season.

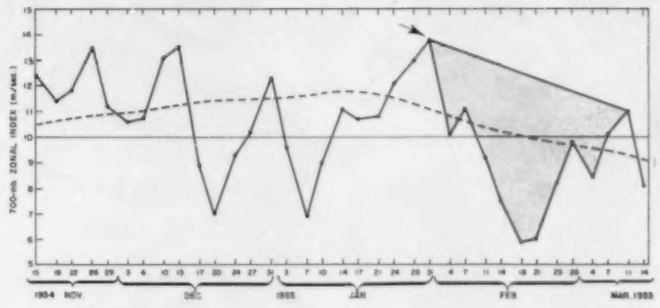

FIGURE 6.—Average strength of 700-mb. westerlies between latitudes 35° and 55° N. over the Western Hemisphere. Solid line connects observed 5-day mean index values (plotted at middle of 5-day period and computed twice weekly), while dashed line shows variation of normal index. Shaded area denotes primary index cycle beginning with the high index period indicated by arrow.

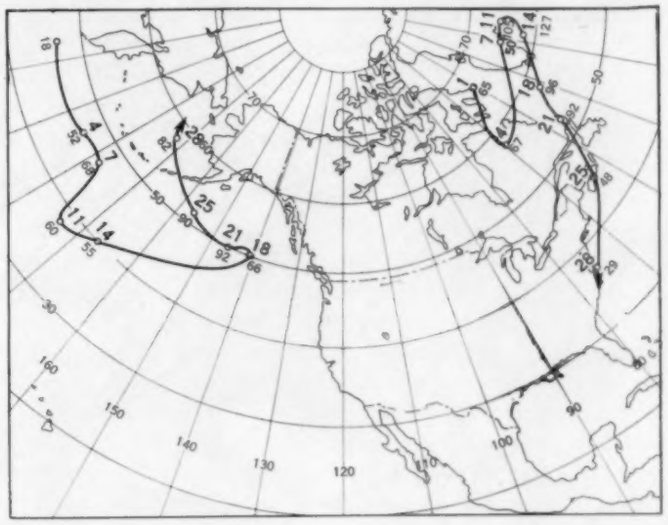

FIGURE 7.—Trajectories of two outstanding centers of positive 700-mb. height anomaly during February 1955. Open circles locate the center of each anomaly on a series of 5-day mean charts computed twice weekly. The large upper number is the middle date of the 5-day period, and small lower number is the intensity of the center in tens of feet. The Atlantic center was more intense than the Pacific center during the first 2½ weeks of the month but less intense during the last week.

3. THE 5-DAY MEAN ANOMALY CENTERS

Both the index cycle and the reversal in circulation during February 1955 can be clarified on the basis of figure 7. This figure gives the paths of the two most prominent centers of positive height anomaly during the month, as obtained from a series of partly overlapping 5-day mean 700-mb. height departure from normal charts prepared twice weekly. The center of each anomaly during each 5-day mean period is plotted as an open circle with the middle day of the period in large numbers above and the central intensity in tens of feet in small numbers below. Both the continuity of these centers from map to map and their resultant trajectories were clear and well-defined during February. This was not true, however, during the adjacent months of January, when the centers formed, or March, when they dissipated.

The zonal index, which measures the strength of the westerlies between latitudes 35° and 55° N. in the longitudes from 0° westward to 180°, was mostly above normal during the first week of February (fig. 6) in part because the two positive anomaly centers of figure 7 were out of the index band, with the Atlantic anomaly being north of 55° N. and the Pacific anomaly west of 180°. The index dropped sharply during the next two weeks as the center of positive anomaly in the Pacific advanced eastward into the Western Hemisphere and northward to 50° N. This decline of the index was aided by marked intensification of the anomaly center in the Atlantic, which reached a maximum intensity of 1270 ft. above normal in the Denmark Strait during the 5-day period centered February 14. Falling index was also associated with the slow southward motion of this anomaly to 55° N., near which latitude it was centered during the periods of index minimum on the 18th and 21st. Rapid increase of the index during the last week of the month was accompanied by marked southward displacement of the Atlantic anomaly center,

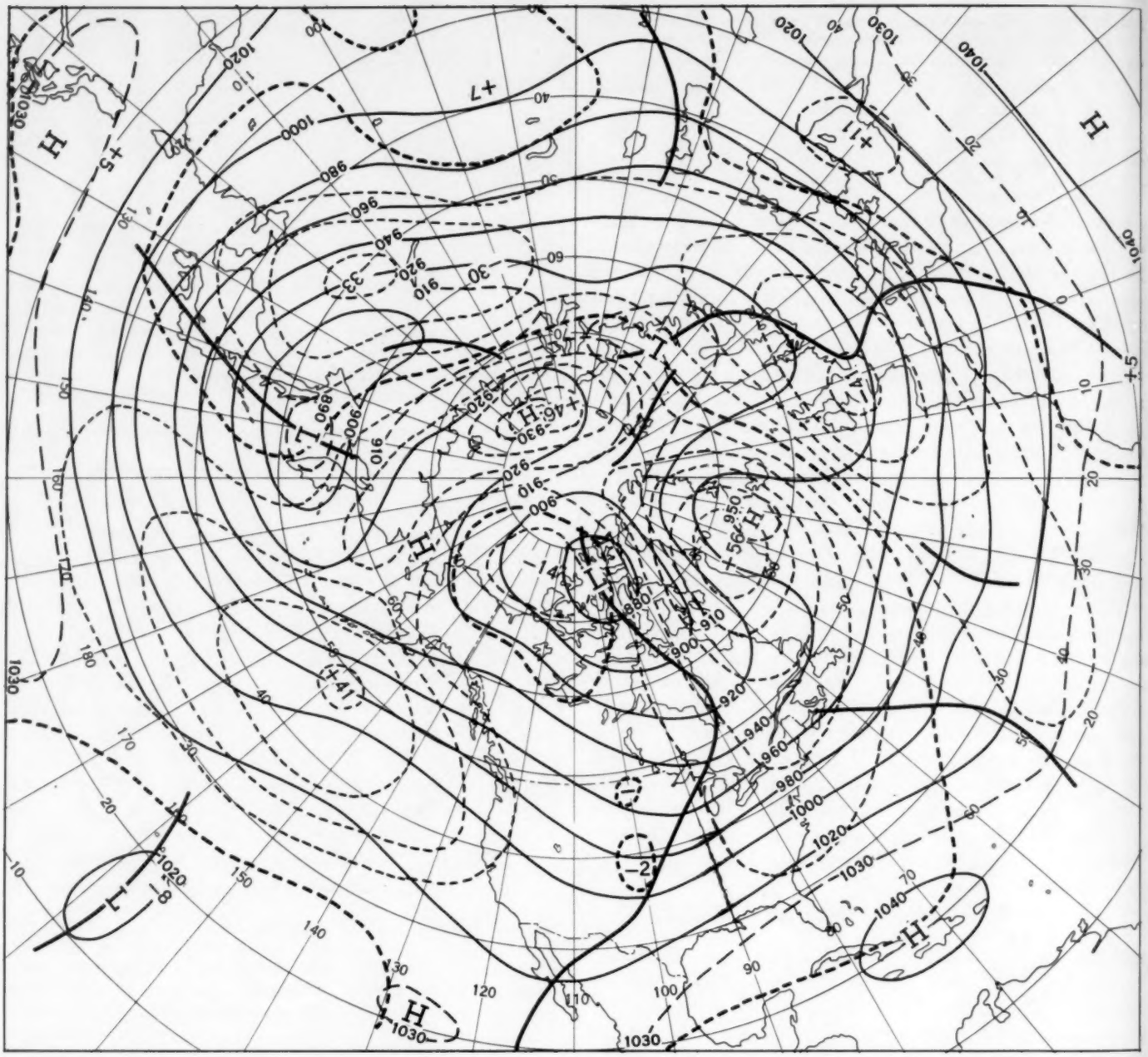

FIGURE 8.—Mean 700-mb. contours and height departures from normal (both in tens of feet) for January 28–February 27, 1955. Outstanding features of hemispheric circulation are blocking Highs over Greenland and Russian Arctic, deep trough in Europe, strong ridge in eastern Pacific, and below normal heights in eastern Asia.

and by motion of the Pacific anomaly center to the northwestern border of our index band.

The 700-mb. circulation during the first half of February (figs. 2A and 4A) reflects the dominant role of the strong positive anomaly which was centered in the vicinity of southern Greenland on every 5-day mean map during the period (fig. 7). At the same time the positive anomaly in mid-Pacific was considerably weaker than the one in the Atlantic. During the third week of the month a transition took place. The Pacific center intensified and entered the critical area south of the Gulf of Alaska where positive height anomalies frequently go with above normal heights on the east coast of the United States, as previously pointed out (see p. 39 and fig. 5). Perhaps in response to this stimulus, the Atlantic anomaly center began to migrate southwestward, from the vicinity of Greenland to Newfoundland and Nova Scotia. By the end of the month this center was located along the Middle Atlantic Coast of the United States, where it was in harmony with large positive departures in the northeastern Pacific. It is interesting to note the marked and steady decrease in central intensity of the Atlantic anomaly as it moved southward, from +1270 ft. on the 14th at 62° N. to +290 ft. on the 28th at 36° N. A similar dependence of intensity upon latitude has been noted by James [8] for daily systems at sea level and by Clapp [9] for 5-day mean 700-mb. height anomaly centers.

4. MONTHLY MEAN CIRCULATION AND WEATHER

The average 700-mb. circulation for the month as a whole reflected the extreme anomalies of the first half of the month (figs. 2A and 4A) in the Atlantic, which was dominated by a strong blocking High over Greenland and below normal heights in the Azores region (fig. 8). In the Pacific and North America on the other hand, the monthly mean map more closely resembled the charts for the second half of the month, when anomalies were largest in these regions, since it was characterized by a stronger-than-normal ridge in the eastern Pacific and a full-latitude trough through the central part of North America. Other noteworthy features of the mean February circulation were a much deeper than normal trough in Europe and below normal heights throughout eastern Asia, south of a blocking ridge in the Arctic.

The monthly mean circulation at the 200-mb. level (fig. 9) closely resembled that at 700 mb. (fig. 8). However the trough over the Japanese Islands and the ridge along the east coast of Alaska at 700 mb. were both displaced westward at 200 mb. In addition, two weak troughs in the Atlantic at low and middle latitudes and the closed High over Greenland at 700 mb. were smoothed out of the 200-mb. picture. The outstanding feature of the isotach analysis at 200 mb. (dashed lines in fig. 9) was the maximum wind speed center over southern Japan, where geostrophic speeds averaged over 70 m./sec. during the month. Another notable feature was the split jet stream in the Atlantic and adjoining continents due to the block over southern Greenland.

The departure of average temperature from normal for the month as a whole (Chart I-B) did not exceed $\pm 2°$ F in most of the eastern half of the United States, where early-period coldness was balanced by abnormal warmth at the end of the month. Nevertheless, monthly mean temperatures generally averaged slightly above normal east of the Mississippi River as a result of the prevalence of southerly and easterly winds, relative to normal, on the monthly mean charts at both sea level (Chart XI inset) and 700 mb. (fig. 8). In the western half of the country, on the other hand, stronger than normal northerly flow at all levels was accompanied by below normal temperatures during both the first and second halves of the month. Negative temperature anomalies for the month as a whole exceeded 10° F. in part of the Great Basin. Cold weather in this area is a frequent concomitant of a strong high cell in the eastern Pacific, where February pressures averaged as much as 16 mb. above normal at sea level (Chart XI inset).

This month's pattern of temperature anomaly in the United States, cold in the west and warm in the east, is usually accompanied by abundant precipitation and cyclonic activity. It is not surprising, therefore, that precipitation during February was generally above normal in most of the United States east of the Continental Divide (Chart III). This heavy precipitation was associated with the presence of a mean trough in the central United States

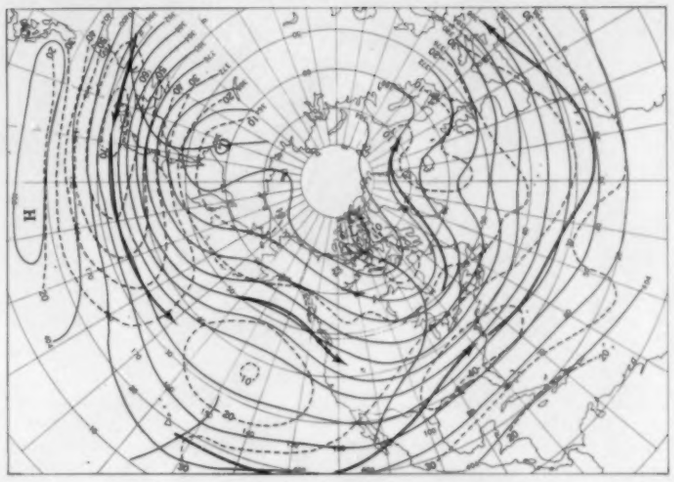

FIGURE 9.—Mean 200-mb. contours (in hundreds of feet) and isotachs (dashed, in meters per second) for January 29–February 27, 1955. Solid arrows indicate the position of the mean 200-mb. jet stream, which was strong and single in the western Pacific but weaker and split in other portions of the map.

at all levels of the troposphere (Charts XI to XV and fig. 9). Stronger than normal southerly flow at sea level and southwesterly flow at 700 mb. ahead of this mean trough transported considerable moisture from the Gulf of Mexico into the eastern half of the country. This moisture was released during widespread cyclonic activity (Chart X) north of the principal jet stream at 200 mb. (fig. 9). During one of these storms, on February 5, New Orleans reported 1 inch of rain in 5 minutes, a new 60-year record for the station. Cyclones were especially frequent in the Central Plains, Ohio Valley, and New England, portions of which had twice the normal amount of precipitation. Much of this fell as snow in northern New England, where Ft. Kent, Maine, reported as much as 58 inches on the ground on February 20. The State with the greatest excess of precipitation in the United States was Kentucky, where Statewide amounts averaged 208 percent of normal.

Moisture from the Pacific and the passage of an unusually large number of cyclones were responsible for heavy snows in the northern half of the Great Plains. More than twice the normal precipitation fell in large parts of Nebraska, South Dakota, Wyoming, and Montana. Upslope action produced by some easterly wind components, relative to normal, at both sea level and 700 mb. was also instrumental in this precipitation. The worst storm of the winter occurred on February 19 when a true blizzard, accompanied by winds up to 70 m. p. h. and temperatures near zero, left up to 14 inches of snow in parts of South Dakota.

In the Southeast, Southern Plains, and Upper Lakes region precipitation amounts were generally subnormal and in some cases less than one-half of normal. In each of these areas the monthly mean vorticity at 700 mb. was more anticyclonic than normal (fig. 10). A fairly good relation between precipitation and relative vorticity at the 700-mb. level on daily charts in the southeastern United

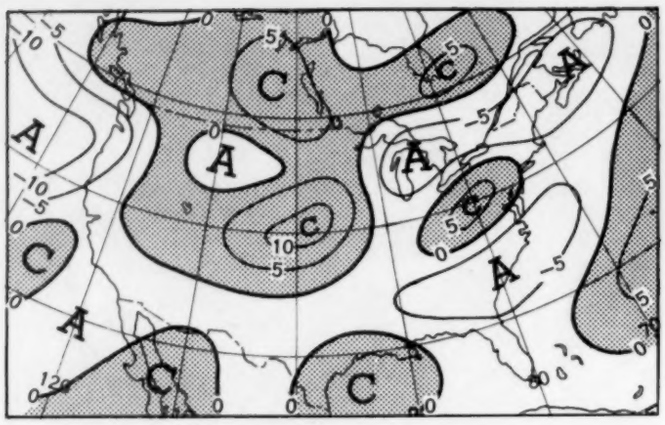

FIGURE 10.—Departure from normal of vertical component of mean geostrophic relative vorticity at 700 mb. for January 29–February 27, 1955, in units of $10^{-6}sec^{-1}$. Areas with greater cyclonic vorticity than normal (shaded and labelled C at center) correspond fairly well with areas of above normal precipitation for month (Chart III). Areas with greater anticyclonic vorticity than normal (labelled A at center) correspond to areas of below normal precipitation.

States was found by Slater [10]. The rain shadow effect contributed to light precipitation in New Mexico, southeast Colorado, southwest Kansas, western Oklahoma, and western Texas, where anomalous mean 700-mb. wind components were northwesterly. In this area of drought less than half the normal precipitation has fallen during the last 7 months.

West of the Continental Divide precipitation was generally subnormal and, in many areas, less than half of normal. Light amounts in this sector were associated with the dominance of dry northerly flow on all but the last few days of the month at all levels from sea level (Chart XI) to 200 mb. (fig. 9). Furthermore, high pressure prevailed at sea level, and mean vorticity at 700 mb. was generally more anticyclonic than normal (fig. 10). The scarcity of cyclones at sea level in the Far West during the month is also noteworthy (Chart X). The driest State in the Nation during February on an absolute basis was New Mexico, with a Statewide average of only 0.35 inch total precipitation. The driest State on a relative basis was Arizona, where Statewide precipitation averaged only 34 percent of normal, and one of the worst duststorms in many years was experienced on the 18th.

One of the highlights of the month's weather on a hemispheric basis was unusual storminess in the Hawaiian Islands, where two Kona Lows, thunderstorms, floods, and strong winds were outstanding features. Total rainfall for the month was above normal on all of the islands except Kauai. The capital city of Honolulu, on Oahu, had more than five times the February normal rainfall, while many stations on the islands of Hawaii and Maui had twice as much rain as normal. The monthly mean circulation responsible for this storminess exhibited an interesting variation with elevation. At sea level (Chart XI) only a weak easterly wave was present. At 700 mb. a closed Low was centered over the Islands, south of the main westerly belt (fig. 8). At 200 mb. an open wave in the westerlies was accompanied by a strong jet stream (fig. 9). Northeast of the Islands, however, a strong ridge prevailed at all levels. As a result, anomalous wind components were easterly in much of the eastern Pacific, a condition well known to be conducive to heavy rain in the Hawaiian Islands. In particular the monthly mean 700-mb. chart was remarkably similar to that found by Stidd [11] to be concomitant with heavy rain on Oahu, since a strong center of positive anomaly was present just south of the Gulf of Alaska at the same time that heights were below normal over the Islands themselves.

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THUNDERSTORMS AND TORNADOES OF FEBRUARY 1, 1955

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1. INTRODUCTION

One of the most death-dealing series of convective storms of the last few years occurred during the afternoon and evening of February 1, 1955—the first day of the 1955 "tornado season." This series of severe local storms, accompanied by tornadoes, destructive winds, hail, and heavy rain first struck near Marianna, Ark, at 1400 CST, roared through Commerce Landing, Miss., across northern Mississippi and on to near Huntsville, Ala., where they evidently dissipated around 1830 CST. The times and locations of these storms are shown in figure 1. Most of the injuries and fatalities caused by these storms occurred in northern Mississippi where over 125 persons were injured and 23 other persons—mostly school children—were killed.

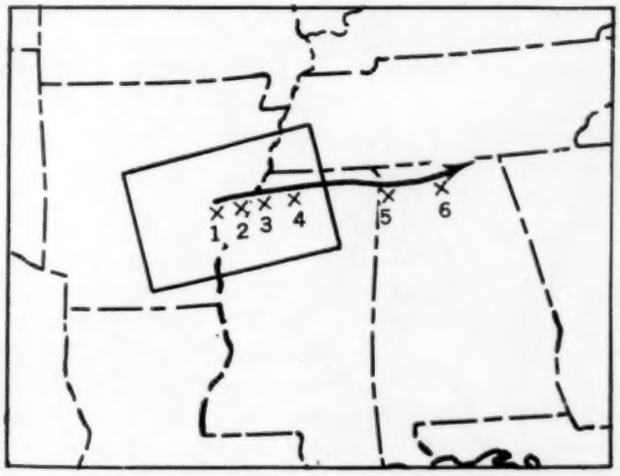

FIGURE 1.—Location and times of reported storms and Severe Local Storms Center tornado forecast area (outlined) on February 1, 1955. Numbered x's signify:

1. 1300 CST, near Stuttgart, Ark. Initial radar echo of squall line.
2. 1400 CST, near Marianna, Ark. Minor damage and some injuries.
3. 1420–1430 CST, Robinsonville and Commerce Landing, Miss. Extensive destruction, several deaths and numerous injuries.
4. 1440–1445 CST, Lewisburg, Miss. Extensive destruction, several deaths, and numerous injuries.
5. 1700 CST, Maud, Barton, and Mynot, Ala. 20 houses severely damaged and several injuries.
6. 1800–1830 CST, near Huntsville, Ala. Minor damage and some injuries.

The purpose of this paper is to describe and illustrate some of the features of this series that are of particular interest in the forecasting of severe local storms. In many respects, this situation presents nearly ideal examples of parameters used in forecasting tornadoes. At the surface, a pronounced Low was moving to the east-northeast at a moderate rate; an mP cold front followed in a V-shaped trough extending south-southwestward; warm, moist air with dewpoints in the 50's was moved northward ahead of the cold front by strong southerly gradient winds; and marked pressure falls occurred ahead of the Low. At the 850-mb. level, a sharp moisture injection, nearly coincident with the temperature ridge [1], was associated with a band of strong winds at this level. One feature of this situation that is different from many tornado outbreaks was the shift in winds at this level from a strong south-southwesterly straight flow at 2100 CST, January 31 to a strong cyclonically-curved flow by 0900 CST February 1. One of the most significant features at the 700-mb. level was the appearance of a moisture "bubble" at Little Rock, Ark. at 0900 CST. At the 500-mb. level, a strong cyclonically-curved jet moved into the area in a nearly ideal manner.

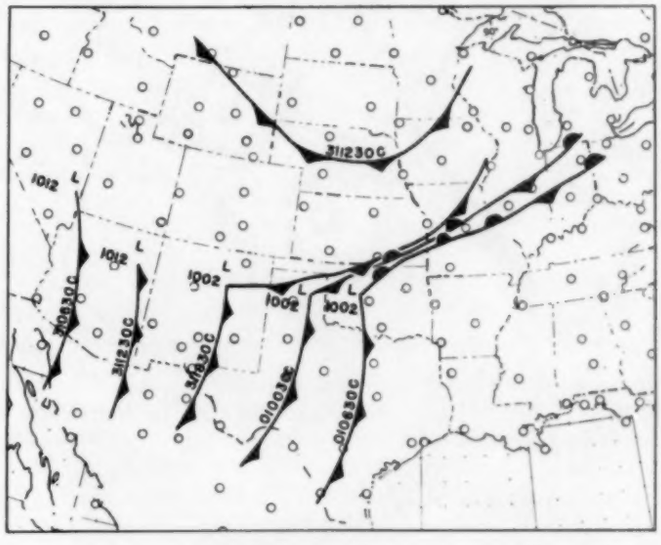

FIGURE 2.—Times and positions of surface fronts and low centers prior to development of storms, 0630 CST, January 31 to 0630 CST, February 1, 1955.

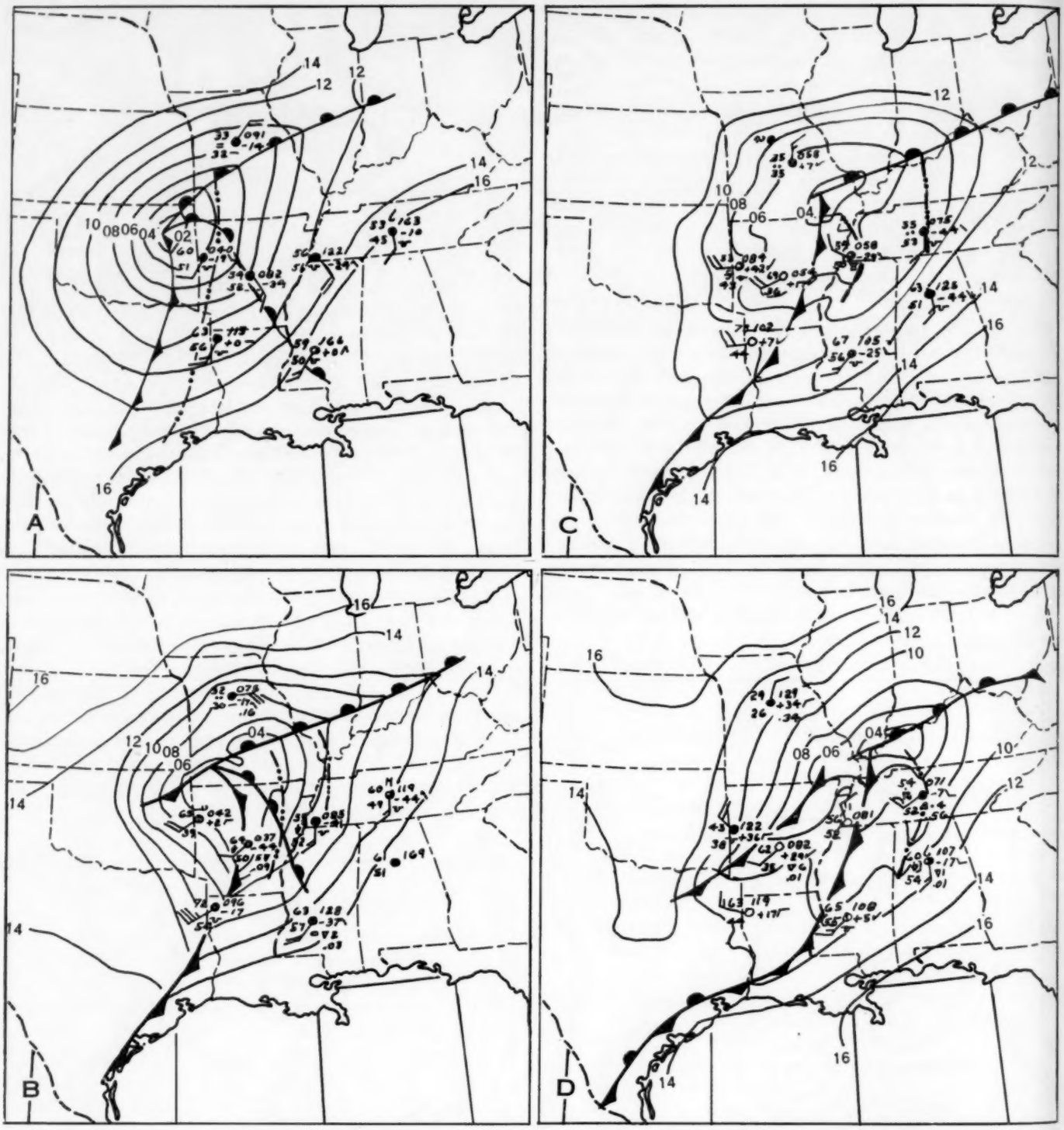

FIGURE 3.—Three-hourly sectional surface maps, February 1, 1955, for (A) 0930 CST, (B) 1230 CST, (C) 1530 CST, and (D) 1830 CST. Analyses are from the Severe Local Storms Center working charts.

2. FEATURES AT THE SURFACE

The surface charts prior to the development of these storms indicate that the associated surface cold front was the leading edge of a mass of Pacific air that entered the west coast early on January 30. The southern portion of this front moved eastward at 20–25 knots to merge with a 1012-mb. low center in central Arizona. The front accelerated to 25–30 knots on January 31 and by noon on February 1 the Low had deepened to 1003 mb. in the vicinity of Springfield, Mo. Positions of the surface fronts and pressure centers prior to the occurrence of the tornadoes are shown in figure 2.

Hourly surface charts which were drawn from 0830 CST through 2030 CST, February 1, are not reproduced here because the 3-hourly maps shown in figure 3 are sufficient for continuity. (Analyses shown here were taken from the Severe Local Storms Center working charts.) The squall line and weak secondary warm front at 0930 CST (fig. 3A) were being followed by Severe Local Storms Center for indications of possible severe storm development. One interesting feature of this series of surface maps is that the relative positions of the surface dew point ridge and the squall line remained nearly coincident throughout the life of the squall line, even in no-precipitation areas.

The low center near Tulsa, Okla. at 0930 CST moved eastward at 45 knots between 0930 and 1230 CST while the cold front and squall line also moved eastward at 45 knots. Around 1230 CST (fig. 3B), the cold front apparently decelerated to 30 knots, and weather activity along the front seemed to decrease, while activity along the squall line began to increase. A micro-low at 1330 CST was detected at the intersection of the squall line and secondary warm front. The echo of a rain area associated with this micro-low was picked up by radar at both Little Rock, Ark. and Memphis, Tenn. As the squall line moved eastward, this echo moved to the northeast and expanded into a line of echoes 70 miles long and 5 miles wide with an isolated echo about 20 miles farther south. When the line of echoes passed over Memphis at 1440 CST, its northern edge was some 25 miles north of Memphis. The storm damage in Arkansas occurred with the passage of the squall line and at its intersection with the secondary warm front. At 1530 CST (fig. 3C), the squall line and its associated severe storms were advancing eastward at 45–50 knots. The micro-low continued to be in evidence and a ridge of high pressure formed between the squall line and the cold front. While the central and northern portions of the squall line were active during the afternoon and evening, the severe damage was confined to the vicinity of the micro-low which continued eastward to the Huntsville, Ala. area by 1830 CST. The center of 3-hourly pressure falls (−4.0 mb.) moved from central Arkansas at 0930 CST to northeastern Alabama (−5.0 mb.) at 1530 CST. These large pressure falls were accompanied by large pressure rises to the west; +6.0 mb. in north central Texas at 0930 CST to +6.0 mb. near Tulsa, Okla. at 1530 CST.

3. FEATURES AT 850 MB.

The positions of the 850-mb. temperature and moisture ridges at various times prior to storm development are shown in figure 4. At 0900 CST, January 31, a warm ridge extended from west Texas to central Nebraska and a moisture ridge was indicated about 300 miles to the east. During the next 24 hours, the warm ridge moved eastward at about 17 knots while the axis of the moisture ridge moved eastward at about 5 knots. At 0900 CST, February 1, the temperature and moisture ridges were approaching coincidence. It is interesting to note that an extrapolation of these positions and movements indicates coincidence near Memphis around 1500 CST. Figures 5A, B, and C show the 850-mb. features at 0900, 1500, and 2100 CST, February 1.

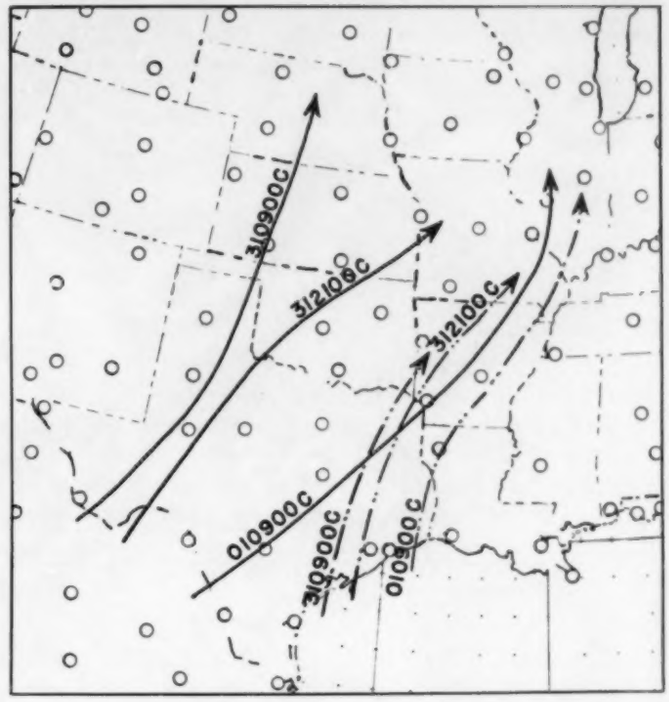

FIGURE 4.—Times and positions of 850-mb. temperature ridge (solid lines) and 850-mb. moisture ridge (dashed lines) prior to development of storms.

An important change in the flow at this level occurred between the charts for 2100 CST January 31, and 0900 CST February 1. The earlier chart (and even 12 hours prior to that) showed a strong moisture injection resulting from a strong south-southwesterly flow from the Gulf of Mexico. However, at 0900 CST, February 1 (fig. 5A) the winds over Arkansas intensified along with the development of marked cyclonic curvature. Such a cyclonic curvature of the flow at this level tends to cut off the northward flow of moisture and is not normally associated with the formation of tornadoes.

4. FEATURES AT 700 MB.

At 700 mb., the line of "no-change", separating the area of apparent warm air advection to the east from the following cold air advection to the west progressed eastward and was generally followed by a 4° C. drop in temperature which tended to decrease the stability of the air mass. The positions of this line at 0900, 1500 and 2100 CST, February 1, are shown in figure 6.

As previously mentioned, one of the significant features at 700-mb. was the "bubble" of moisture that suddenly appeared over Little Rock as indicated by data at 0900 CST, February 1. Such a high moisture value (dew point of −4° C.) could not have resulted from horizontal advection since prior upstream values were much lower.

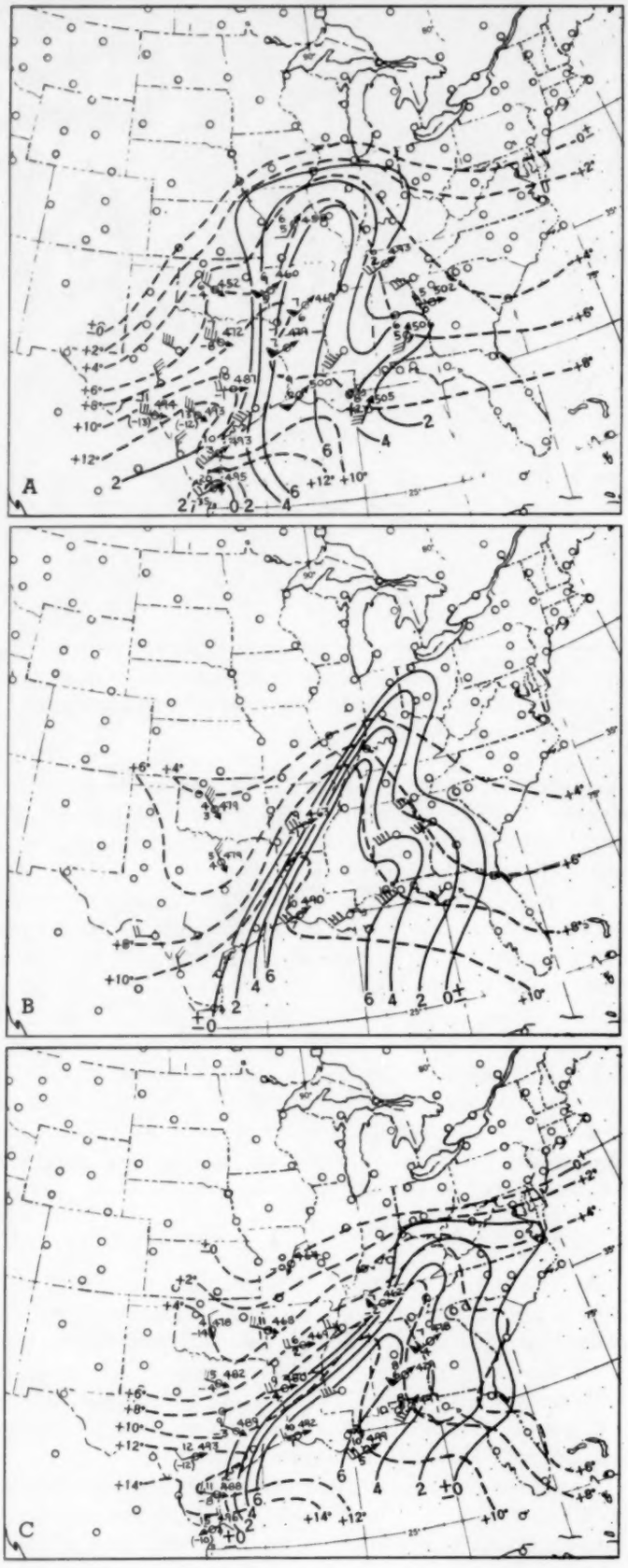

FIGURE 5.—850-mb. charts for February 1, 1955, showing isotherms (dashed) and dew point lines (solid) for 2° C. intervals at (A) 0900 CST, (B) 1500 CST, and (C) 2100 CST.

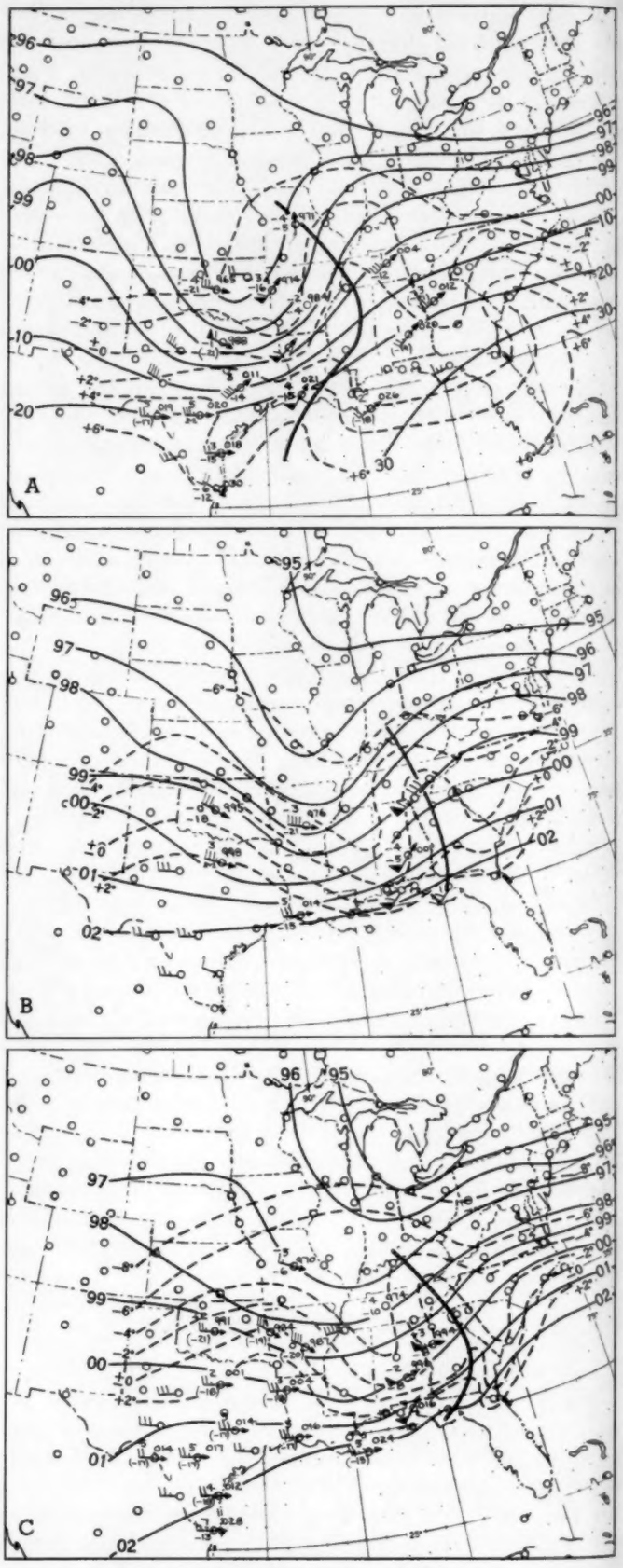

FIGURE 6.—700-mb. charts for February 1, 1955, showing contours (light solid lines) for 100-ft. intervals, isotherms (dashed lines) for 2° C. intervals and the "no-change" line (heavy solid line) at (A) 0900 CST, (B) 1500 CST, and (C) 2100 CST.

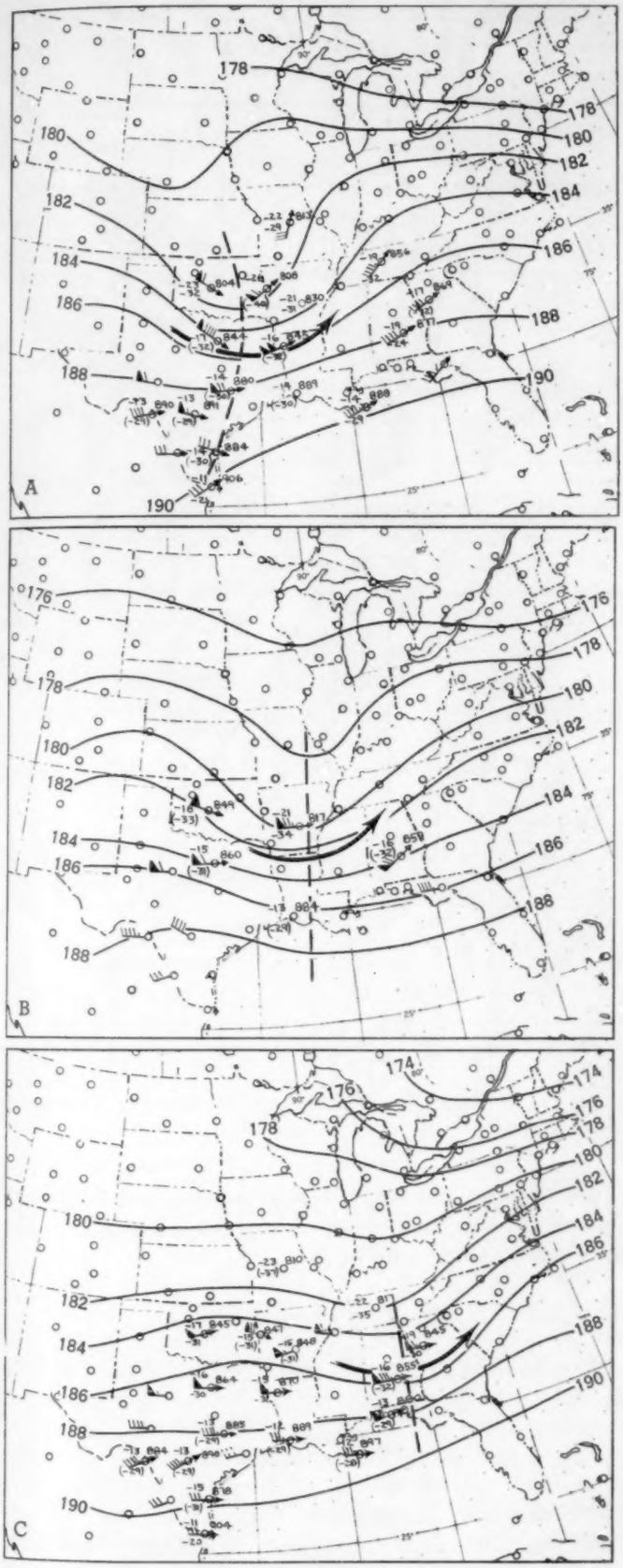

FIGURE 7.—500-mb. charts for February 1, 1955, showing contours (solid lines) for 200-ft. intervals, trough line (dashed) and the current jet position (curved arrow) at (A) 0900 CST, (B) 1500 CST, and (C) 2100 CST.

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Thus it must have been a consequence of an increase in depth of the moist layer through vertical motions rather than horizontal advection.

5. FEATURES AT 500 MB.

The 500-mb. charts for 0900, 1500 and 2100 CST, February 1, are shown in figure 7. The times and positions of the 500-mb. jet and trough lines, taken from the Severe Local Storms Center working charts, are shown in figure 8. According to the model of jet structures proposed by Beebe and Bates [2], the left front quadrant of a 500-mb. jet axis maximum with cyclonic curvature, being an area of divergence at this level, is a contributing factor in effecting the release of convective instability. The jet positions shown at both 0900 and 1500 CST would require positioning a potential severe local storms forecast area to the left (north) of the indicated 500-mb. jet.

6. UPPER AIR CONDITIONS

The Little Rock upper air soundings showed the depth of the moist layer to be near 5,000 feet at both 0900 CST (fig. 9A) and 2100 CST (fig. 9B) on January 31. However, a marked change occurred during the next 12 hours and by 0900 CST February 1 (fig. 9C), the moisture had penetrated to a much greater depth, at least 13,000 feet. At Barksdale Air Force Base, Shreveport, La., a similar situation was noted in the soundings. During the 6-hour period from 2100 CST, January 31 (fig. 10A) to 0300 CST, February 1 (fig. 10B), the depth of the moist layer remained near 5,000 feet. During the next 6-hour period, the moisture depth increased to near 8,000 feet (fig. 10C). If the base of the Barksdale inversion noted at 0300 CST were lifted 80 mb. to the 770-mb. level, the same temperature would be obtained as that observed. Further study of the changes in the lower levels of the air mass represented by the difference of the Barksdale sounding at 0900 CST from

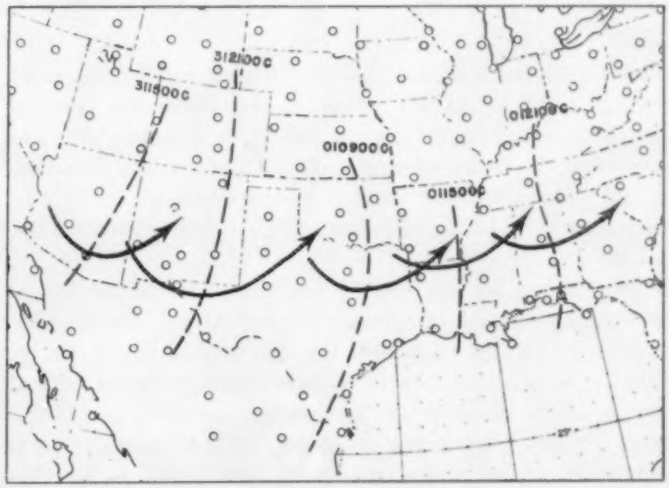

FIGURE 8.—Times and positions of the 500-mb. trough (dashed line) and jet (heavy arrow) prior to and during the development of storms, 1500 CST January 31 to 2100 CST February 1, 1955.

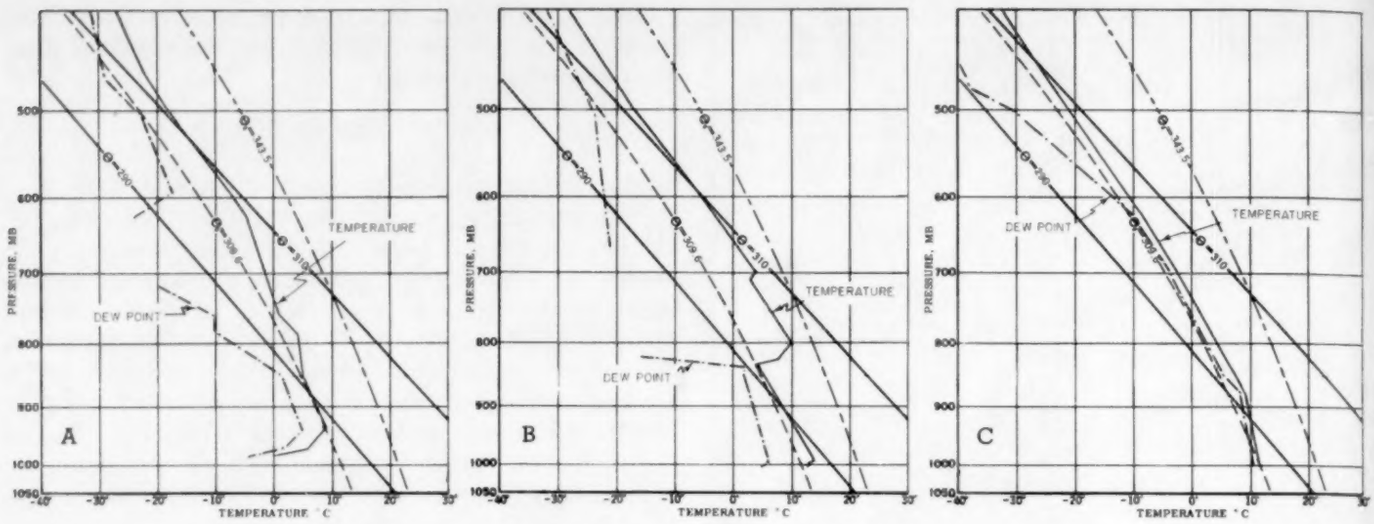

FIGURE 9.—Upper air soundings at Little Rock, Ark. at (A) 0900 CST, January 31, (B) 2100 CST, January 31, and (C) 0900 CST, February 1, 1955.

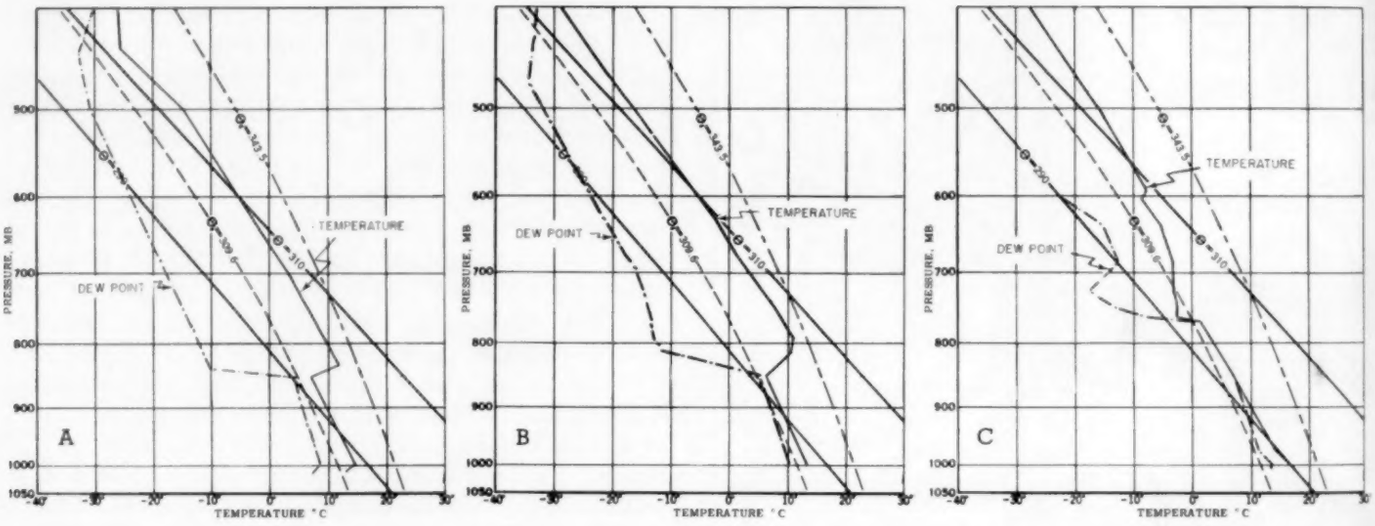

FIGURE 10.—Upper air soundings at Barksdale Air Force Base, Shreveport, La., at (A) 2100 CST, January 31, (B) 0300 CST, February 1, and (C) 0900 CST, February 1, 1955.

that at 0300 CST indicate that this change can be explained through a lift of 80 mb. Considering the moist layer of the Little Rock sounding at 2100 CST, January 31, and increasing the mean temperature by 2° C. and the mixing ratio by 1 gram, the sounding observed at 0900 CST, February 1 could be obtained by lifting the lower 5,000 feet by 150 mb.

One interesting feature of the 0900 CST soundings at Barksdale, Maxwell Air Force Base at Montgomery, Ala., Burrwood, La. and Atlanta, Ga. (all within the warm air mass), was the presence of a superadiabatic lapse rate at the top of the moist layer (base of the inversion). At this time, the moist layer was around 7,500 feet deep except at Burrwood where the depth was near 5,000 feet. The relative humidity at the base of these superadiabatic lapse rates varied from 90 to 100 percent at Barksdale and Maxwell to around 70 percent at Atlanta and Burrwood. Precipitation was not observed at these stations just prior to or during these soundings.

7. FORECASTING TORNADO DEVELOPMENT

The forecasting of this tornado development by the Severe Local Storms Center was based largely upon (1) the recognition of the strong dynamic factors evidenced on the earlier charts (strong 850- and 500-mb. jet structures and intensification of the surface Low over Oklahoma); (2) a prognostic sounding for northeastern Arkansas which took into account a lift of 100 mb.; and (3) the confirmation at 0900 CST by both the Barksdale and Little Rock soundings that the lower layer was undergoing lifting. Actually, the 0900 CST Little Rock sounding

evidenced a greater lift than 100 mb. (at least 150 mb.), while the Barksdale sounding showed less than 100-mb. lift, so that the lifting mechanism was even more potent than expected from earlier data. Also, these considerations pointed to a threat area to the east of Little Rock. Static instability indices at 2100 CST, January 31, were all positive but by 0900 CST, February 1 the Showalter stability index [3] lowered to −1 at Little Rock and to −5 at Ft. Smith, Ark. The lifted index (similar to the Showalter index but determined by moisture and temperature values in the lower 3,000 feet rather than at 850 mb.) on the prognostic sounding for 1500 CST was −4 with a level of free convection around 880 mb. While only a moderate degree of instability was available, the indications of a very strong dynamic modification of the air mass tipped the balance in favor of a forecast for tornadoes rather than severe thunderstorms.

The area was determined largely through the positions expected to be swept out by both the divergent quadrant (left, front) of the jet maximum at 500 mb. and the convergent quadrant (left, rear) of the jet maximum at 850 mb. These considerations, plus the Little Rock sounding and prognostic positions of the surface Low, located an area to the left (north) of both the 850- and 500-mb. jets. In such cases the cut-off between violent convective activity and little activity would be expected to be sharply drawn at, and to the right (south) of, the upper jet axis. The forecast area and reported storms are shown in figure 1.

ACKNOWLEDGMENTS

The author wishes to acknowledge the information on these storms furnished by A. L. King and G. T. Stephens of Memphis, Tenn., and the help extended by R. G. Beebe and D. C. House of the Severe Local Storms Center, Kansas City, Mo.

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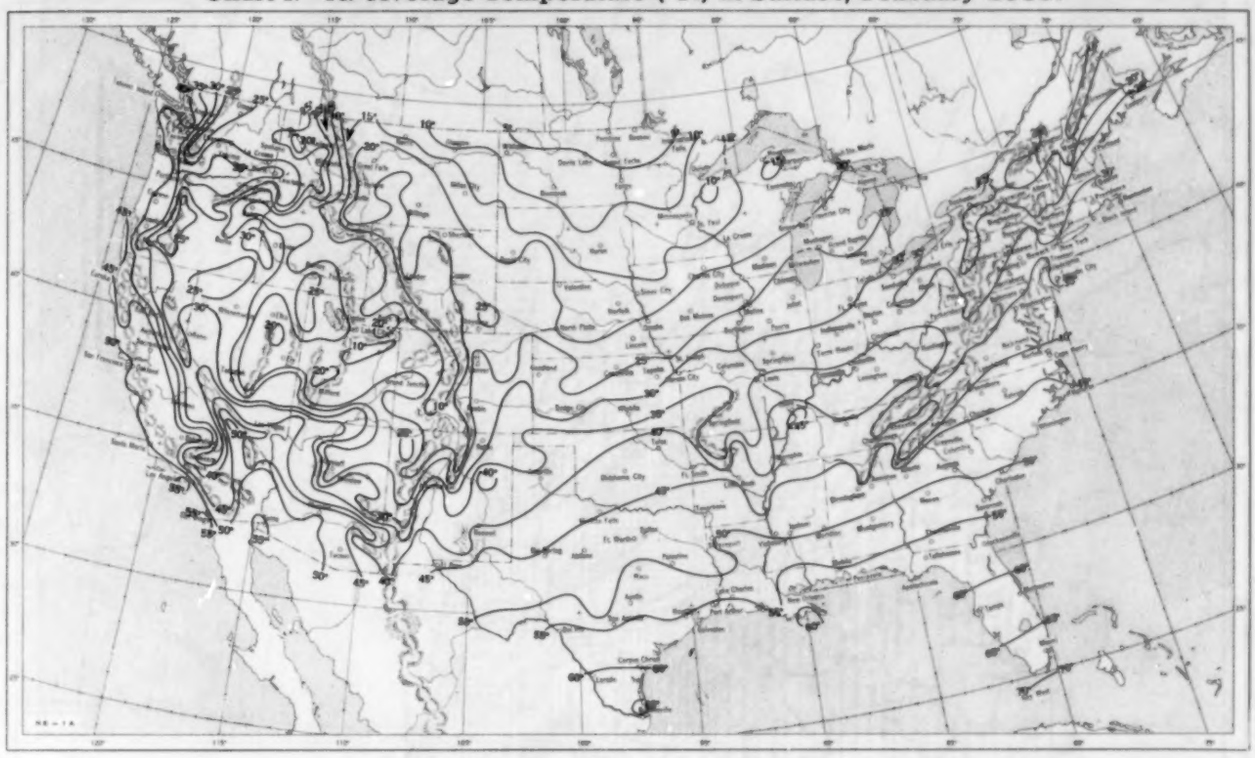
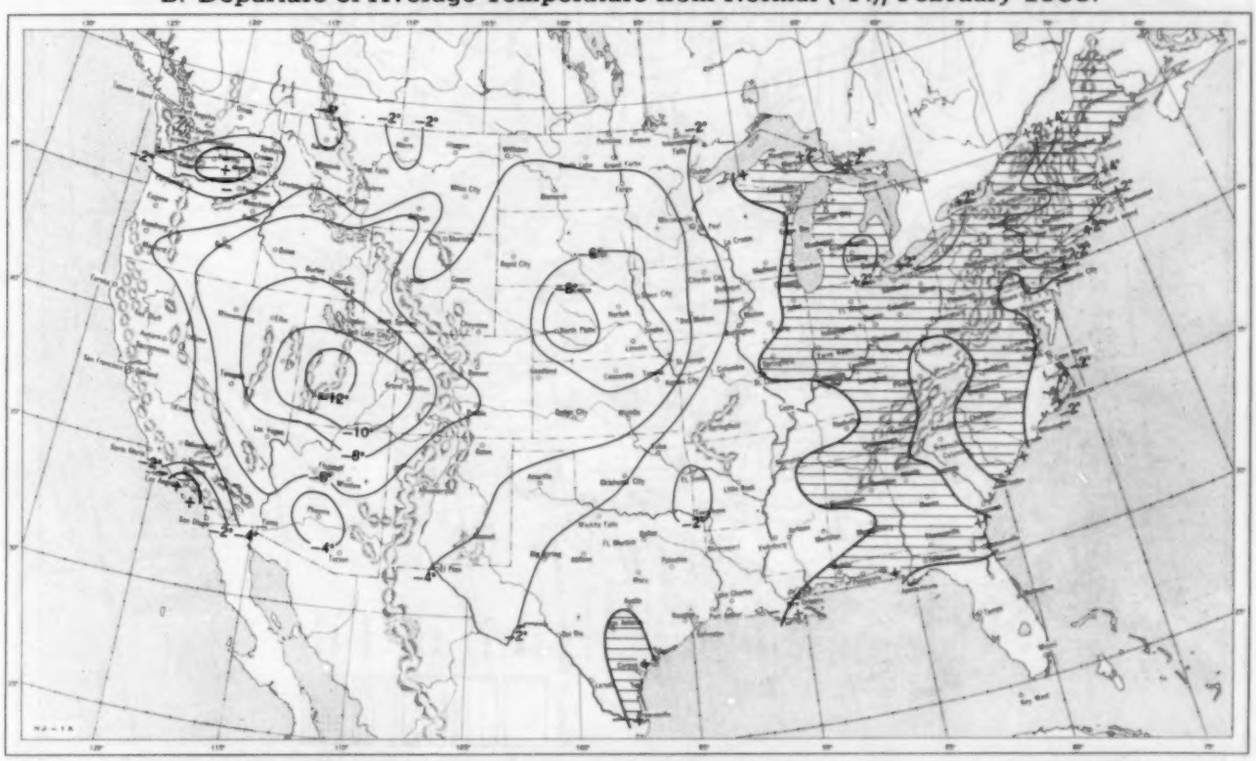
1. Marion E. Crawford, "A Synoptic Study of Instability Lines," *Bulletin of the American Meteorological Society*, vol. 31, No. 10, Dec. 1950, pp. 351–357.
2. R. G. Beebe and F. C. Bates, "A Mechanism for Assisting in the Release of Convective Instability," *Monthly Weather Review*, vol. 83, No. 1, Jan. 1955, pp. 1–10.
3. A. K. Showalter, "A Stability Index for Thunderstorm Forecasting," *Bulletin of the American Meteorological Society*, vol. 34, No. 6, June 1953, pp. 250–252.

U. S. GOVERNMENT PRINTING OFFICE: 1955

Chart I. A. Average Temperature (°F.) at Surface, February 1955.

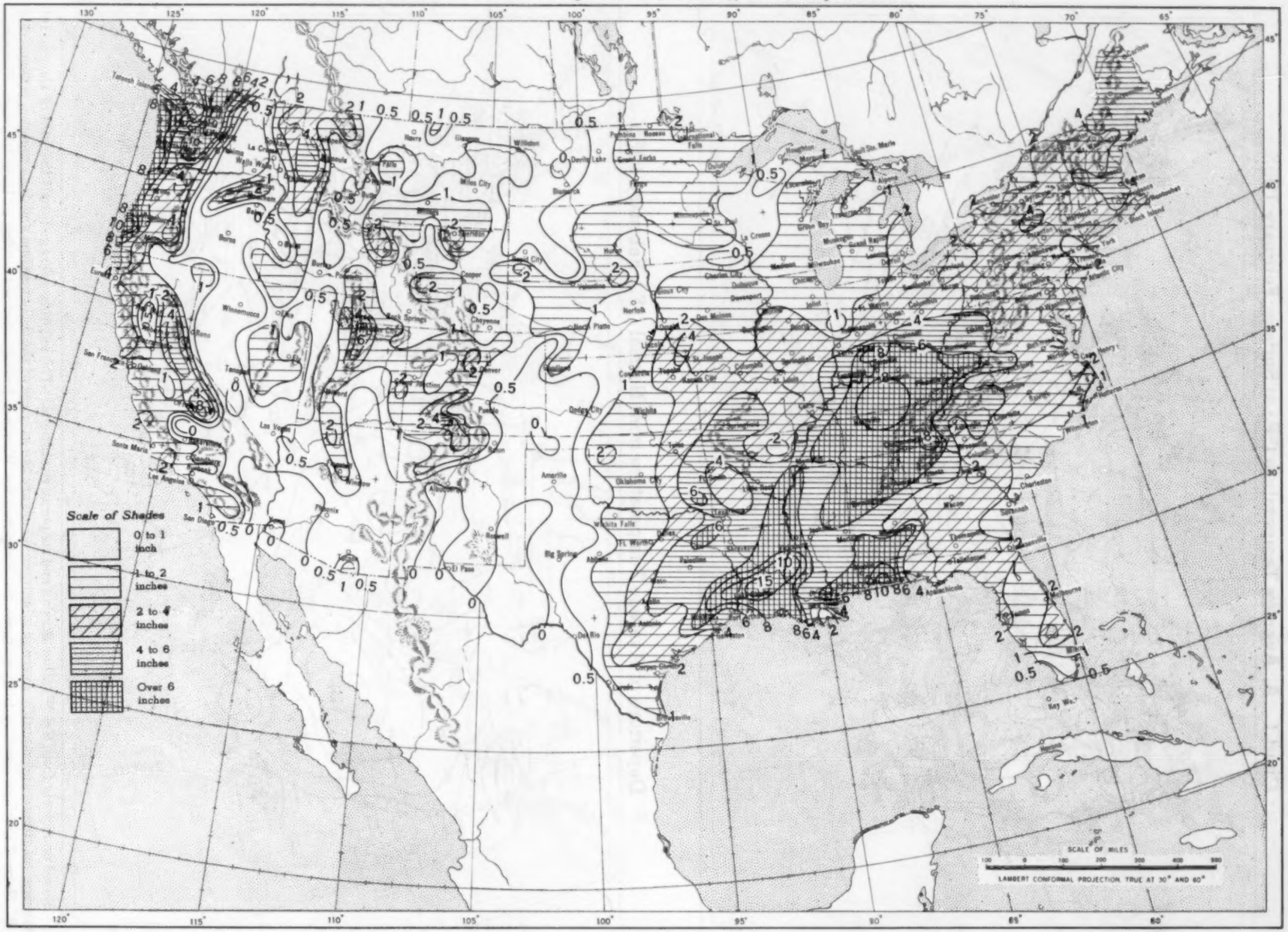


B. Departure of Average Temperature from Normal (°F.), February 1955.



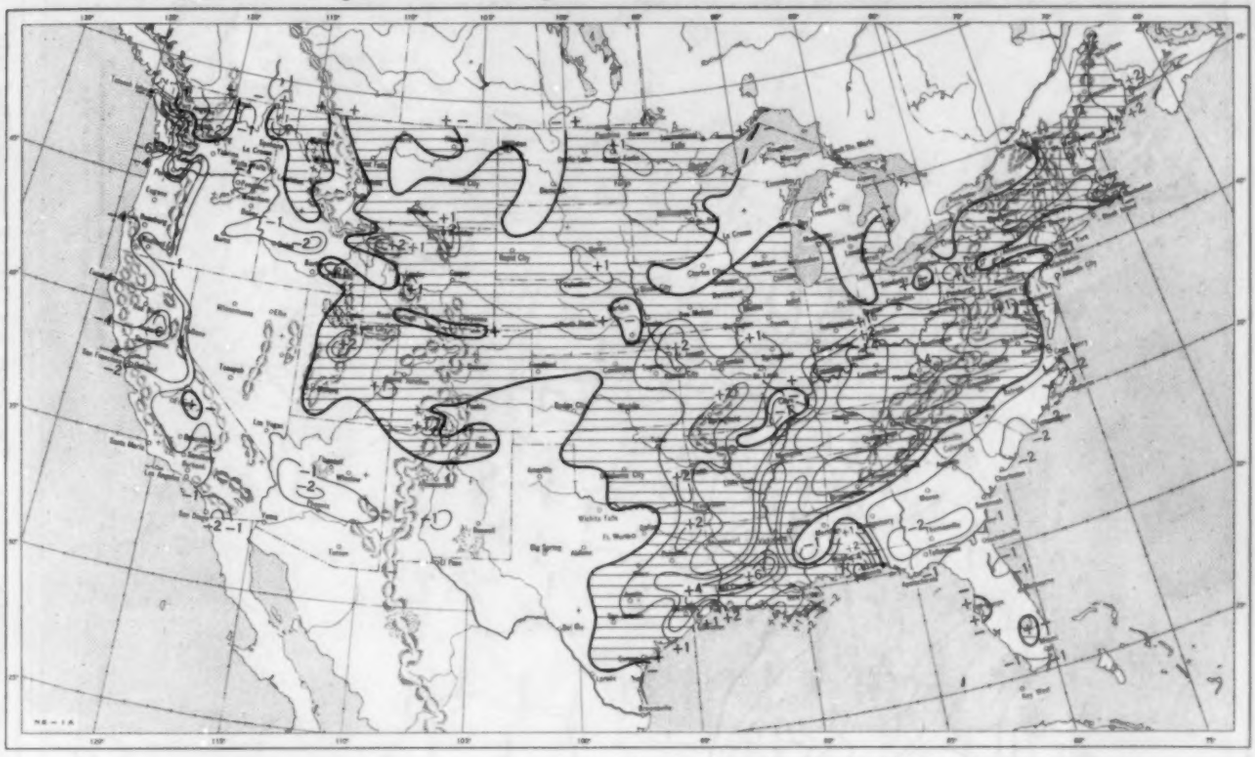
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), February 1955.

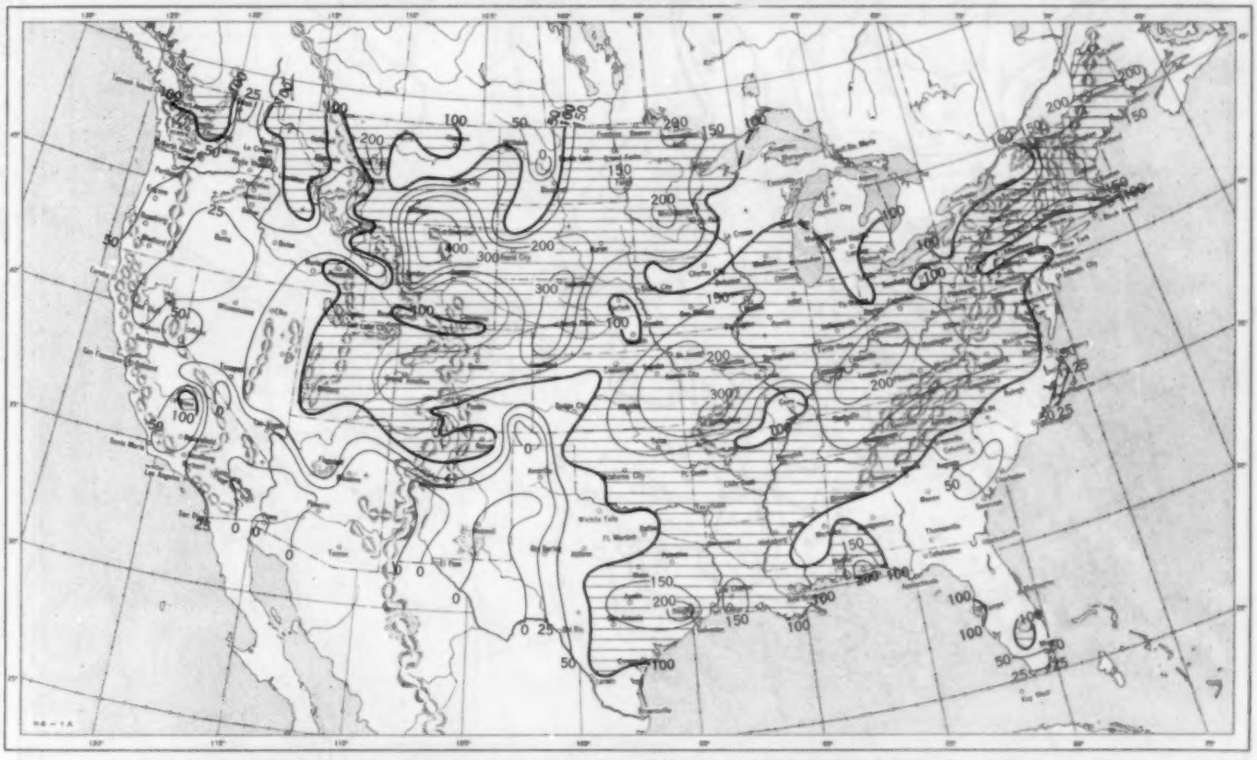

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION, TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), February 1955.

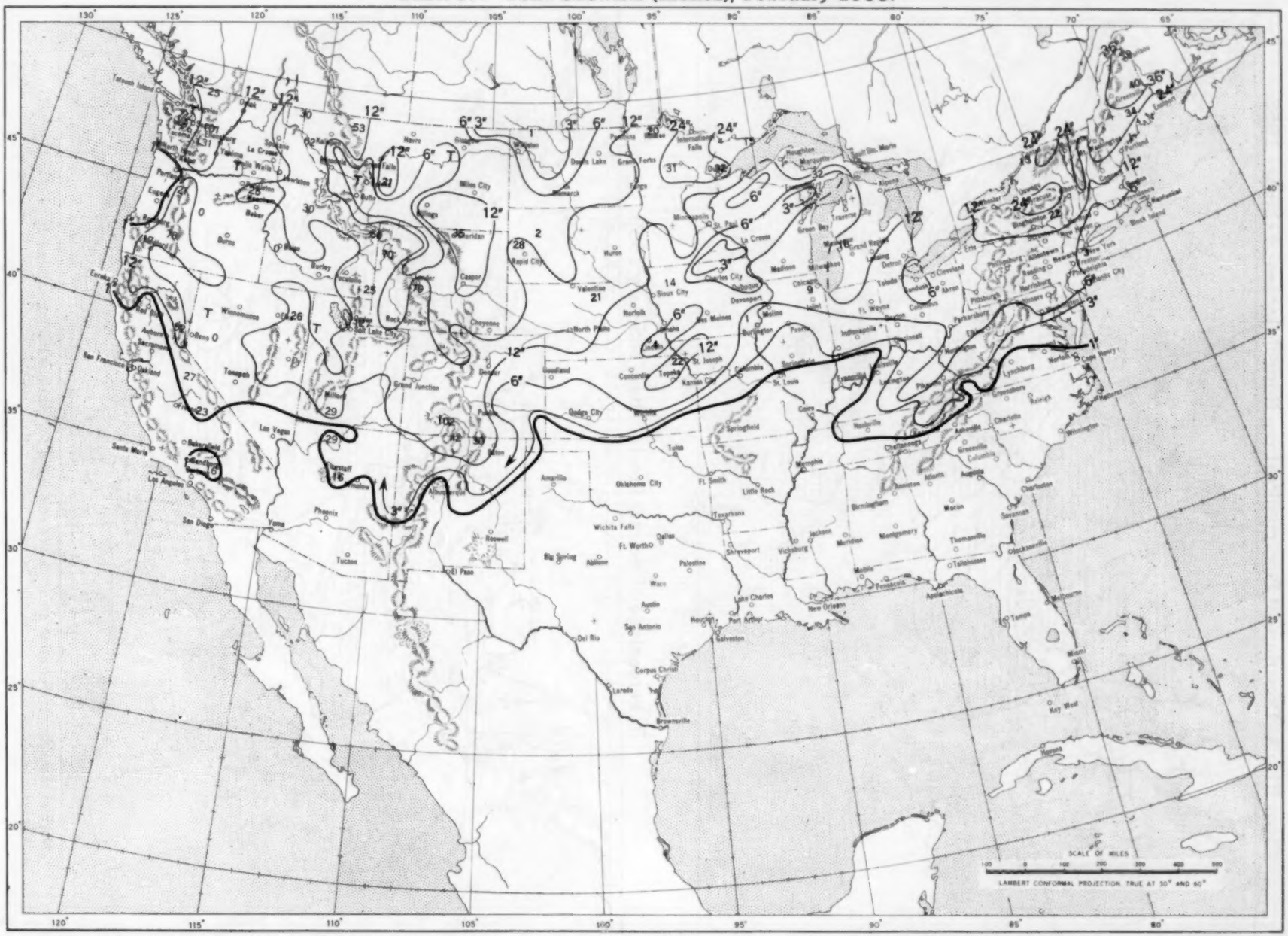


B. Percentage of Normal Precipitation, February 1955.



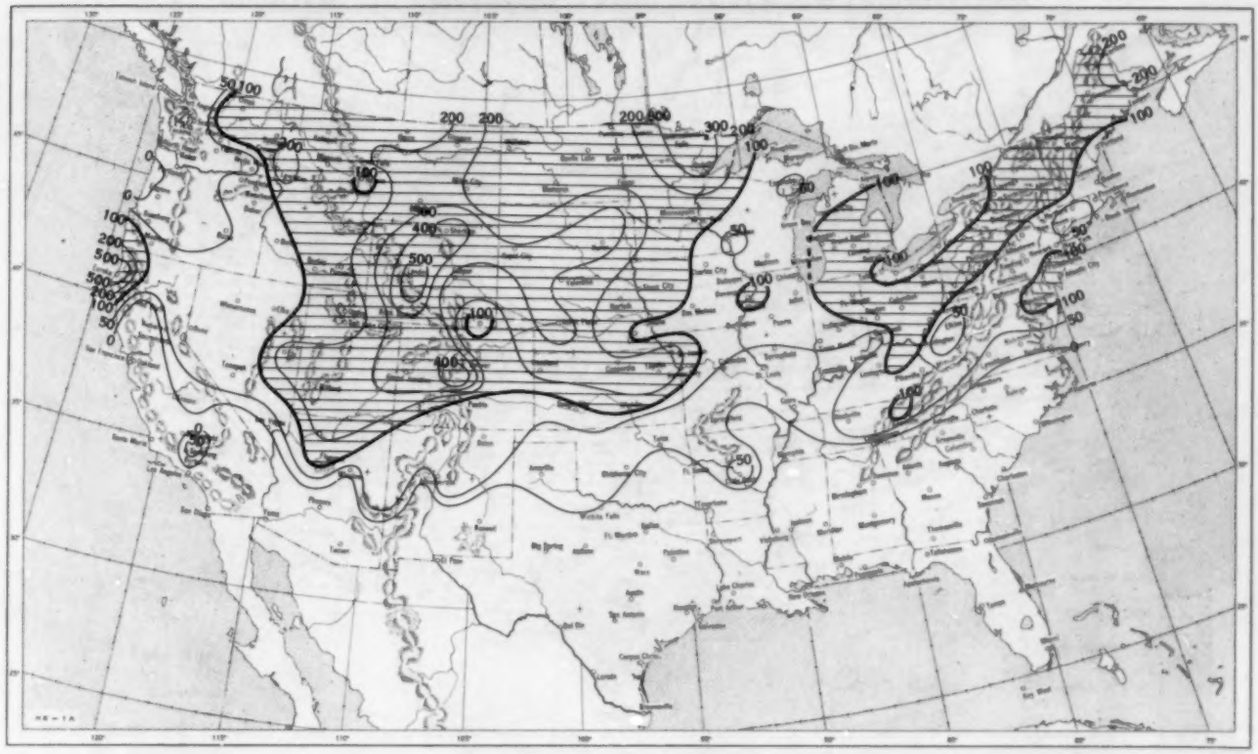
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), February 1955.

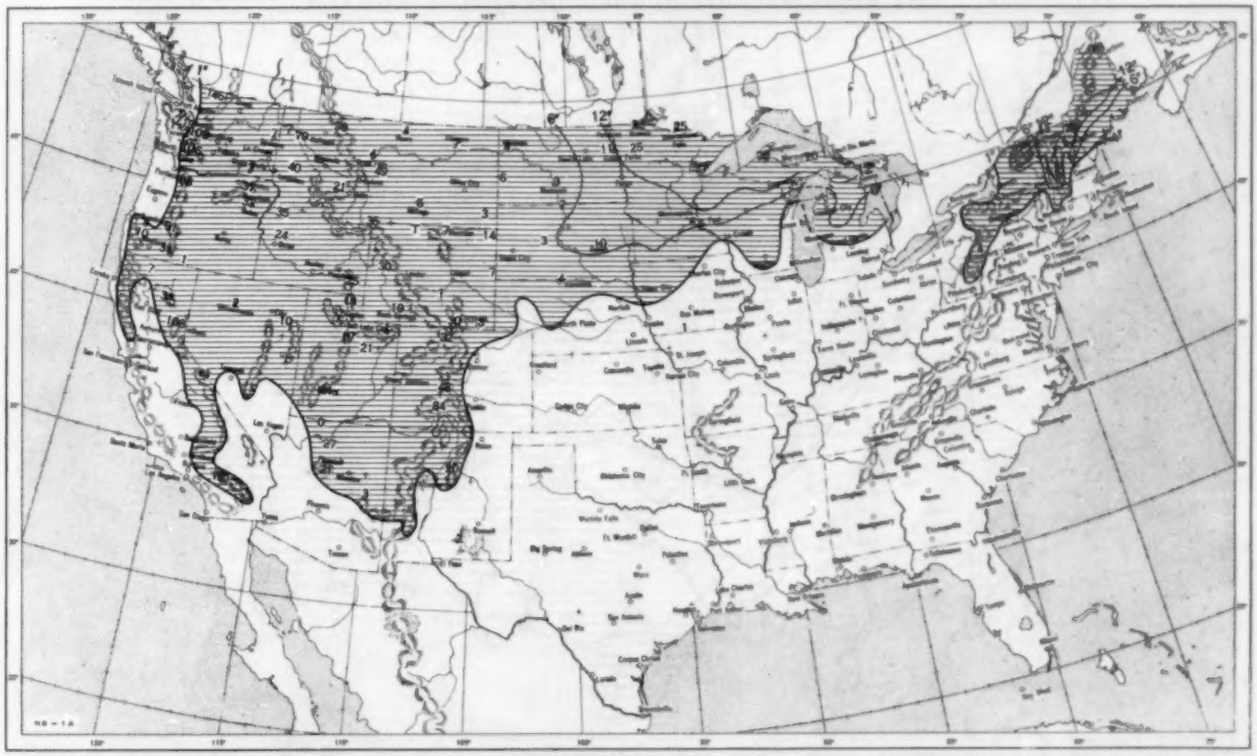


This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V. A. Percentage of Normal Snowfall, February 1955.

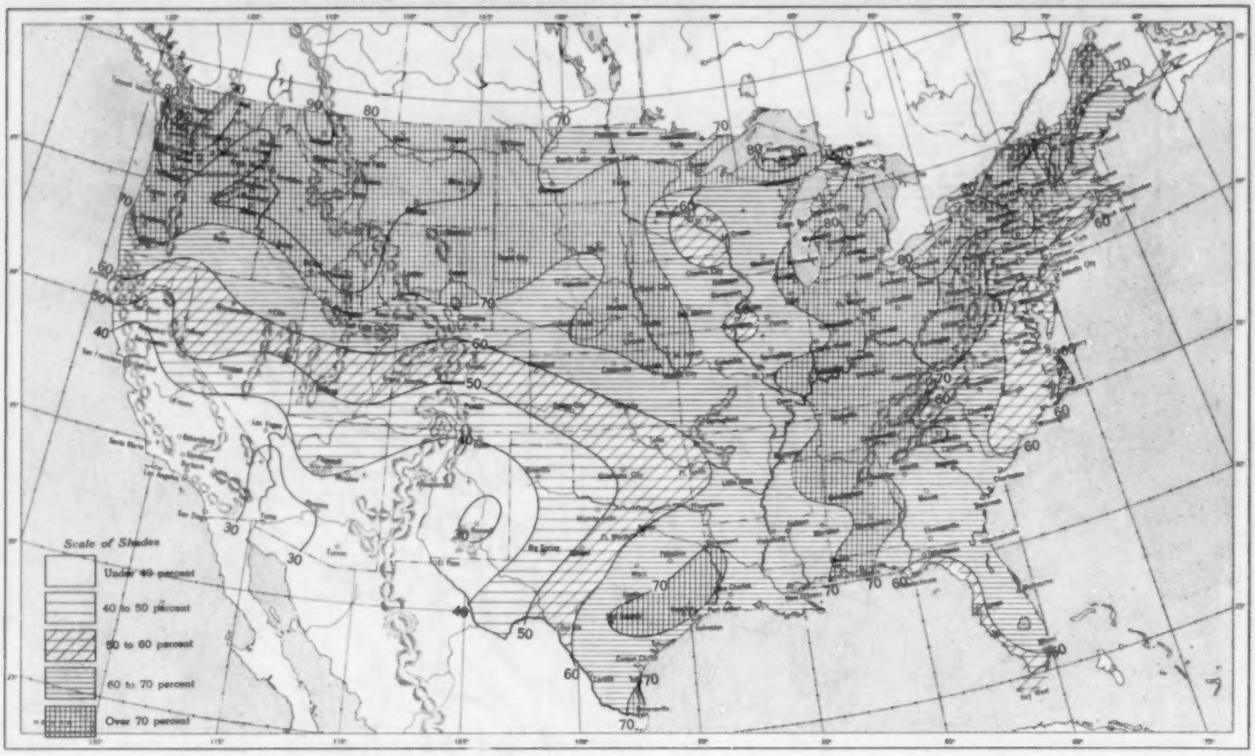


B. Depth of Snow on Ground (Inches). 7:30 a. m. E. S. T., February 28, 1955.

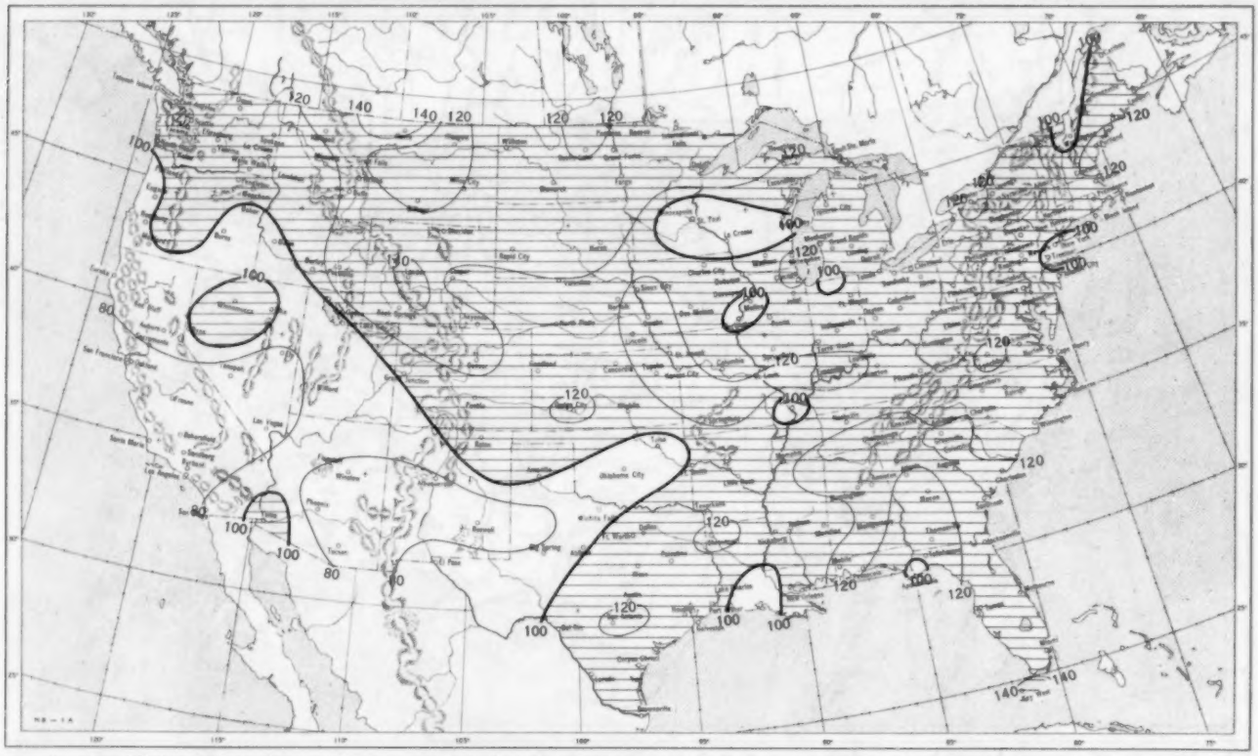


A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E. S. T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, February 1955.

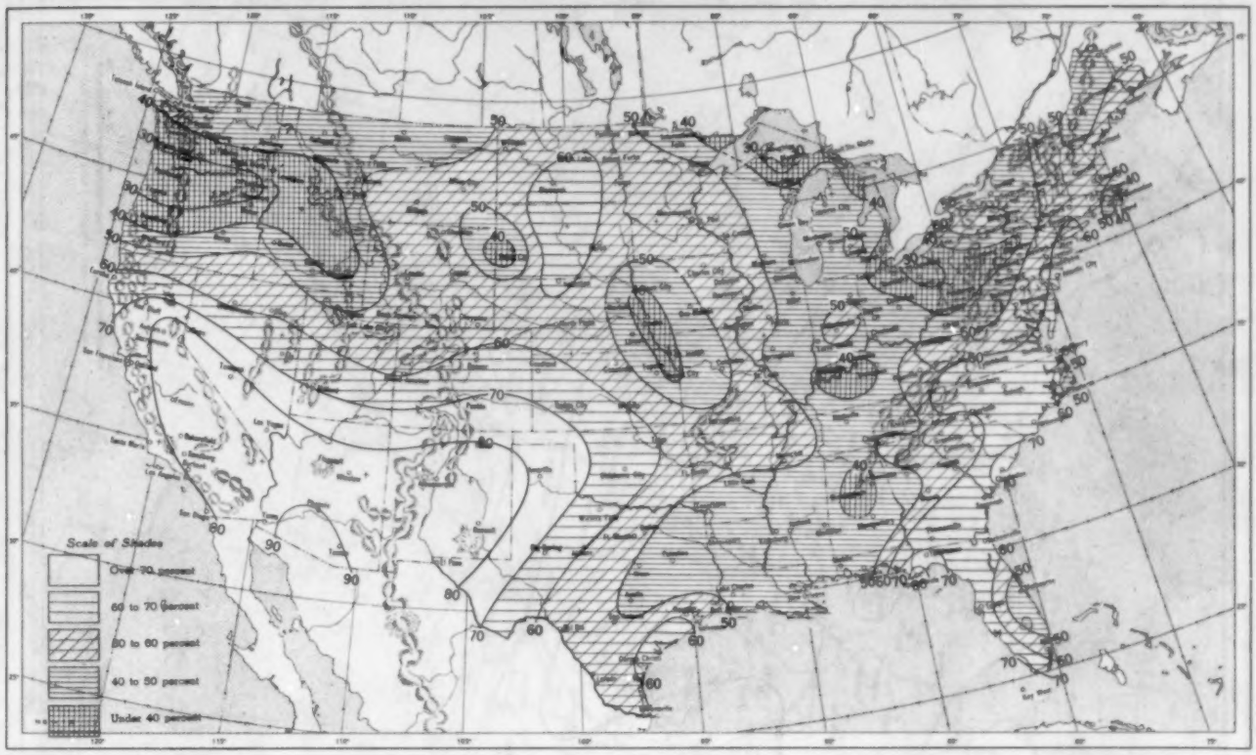


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, February 1955.

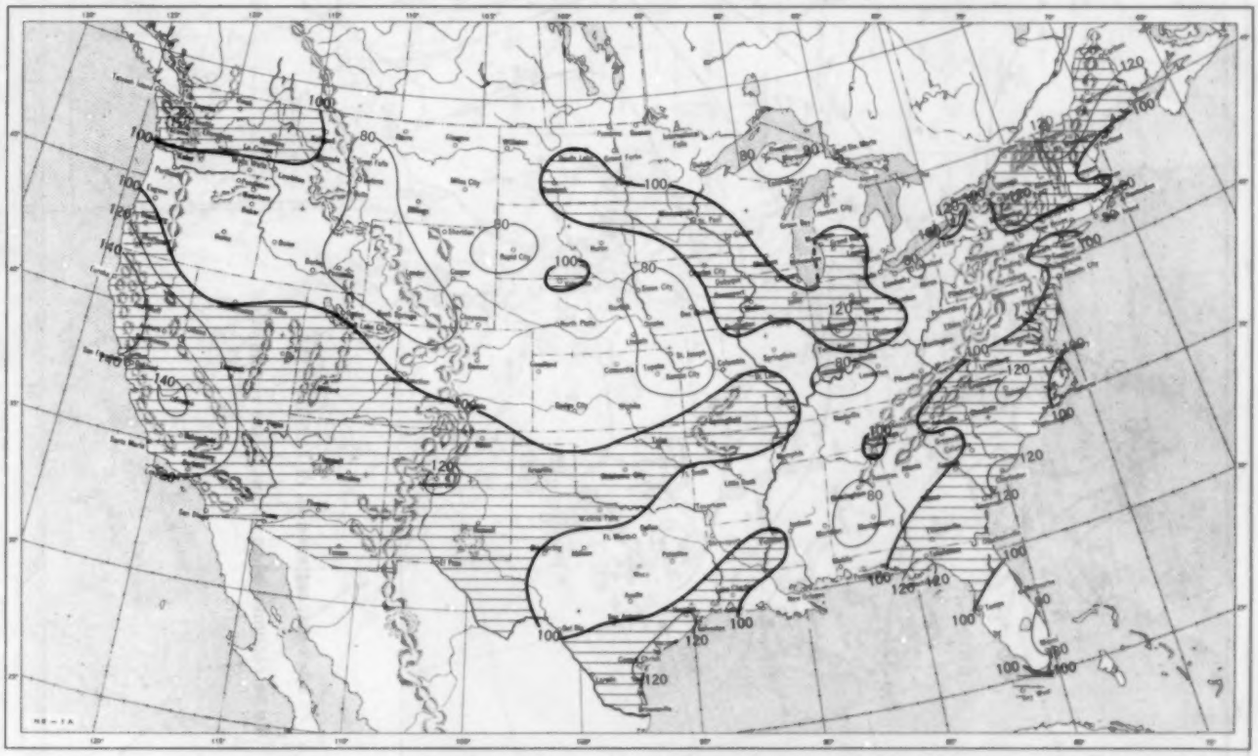


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, February 1955.



B. Percentage of Normal Sunshine, February 1955.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, February 1955. Inset: Percentage of Normal Average Daily Solar Radiation.

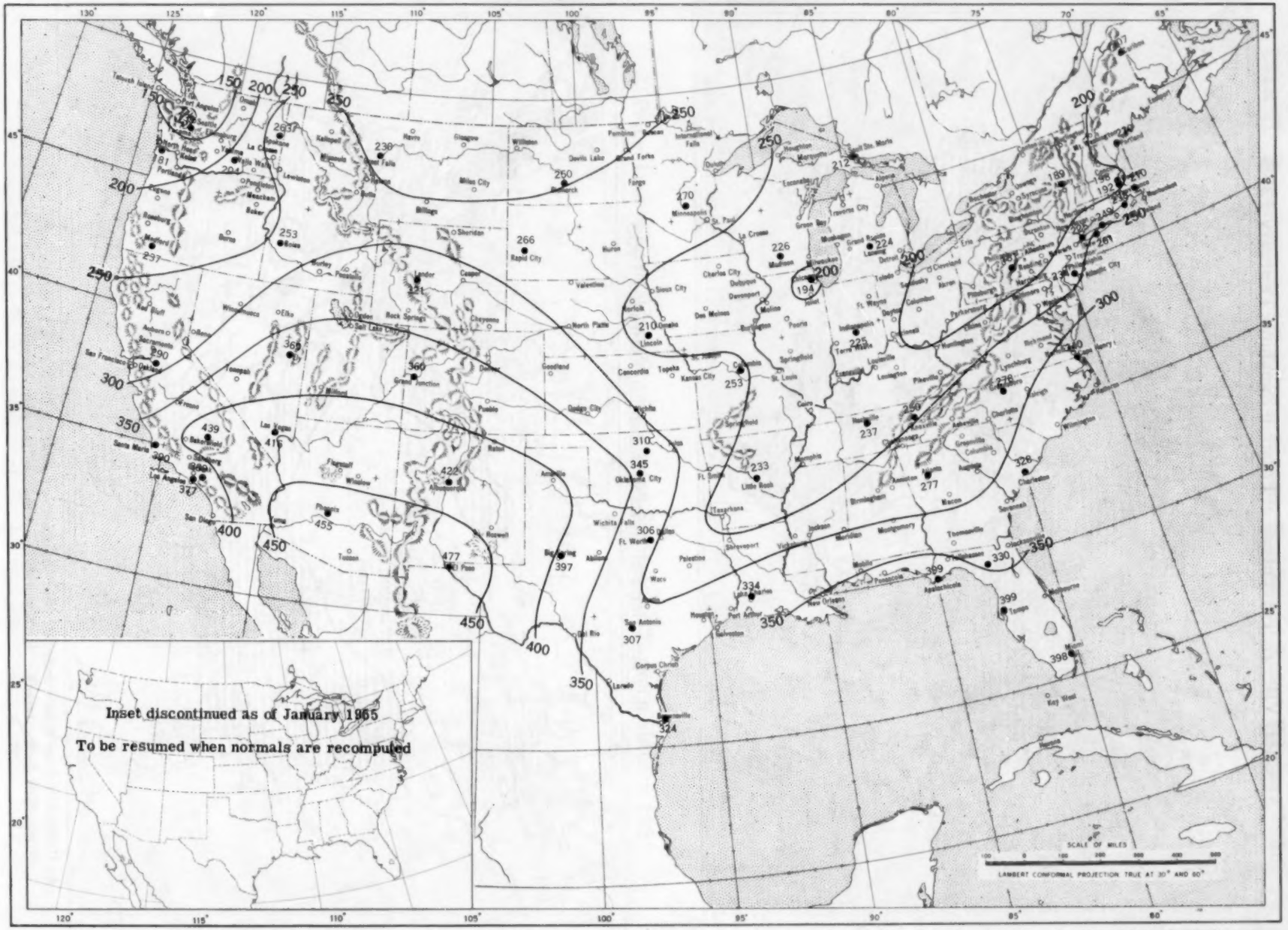
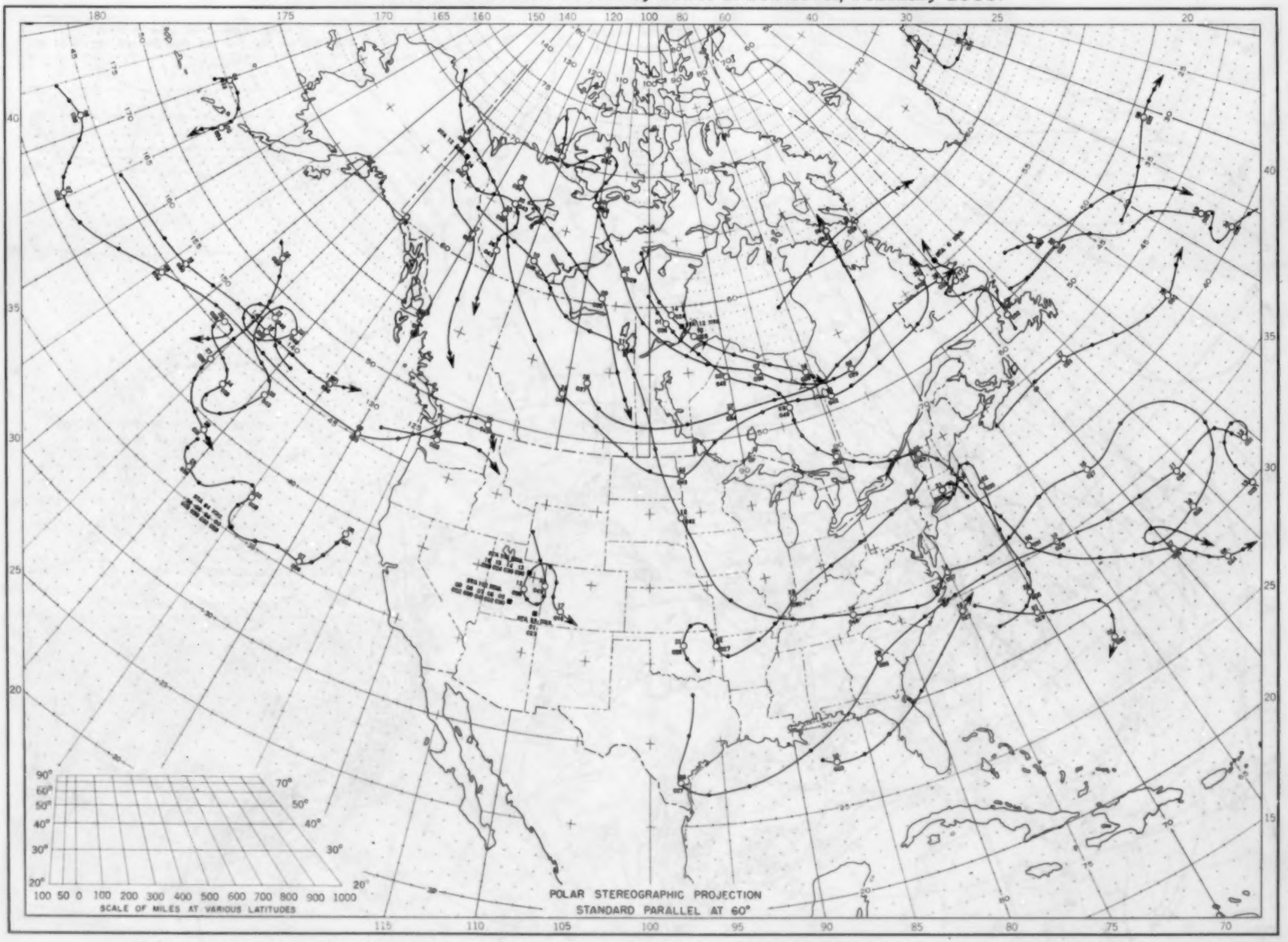

Inset discontinued as of January 1965
To be resumed when normals are recomputed
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

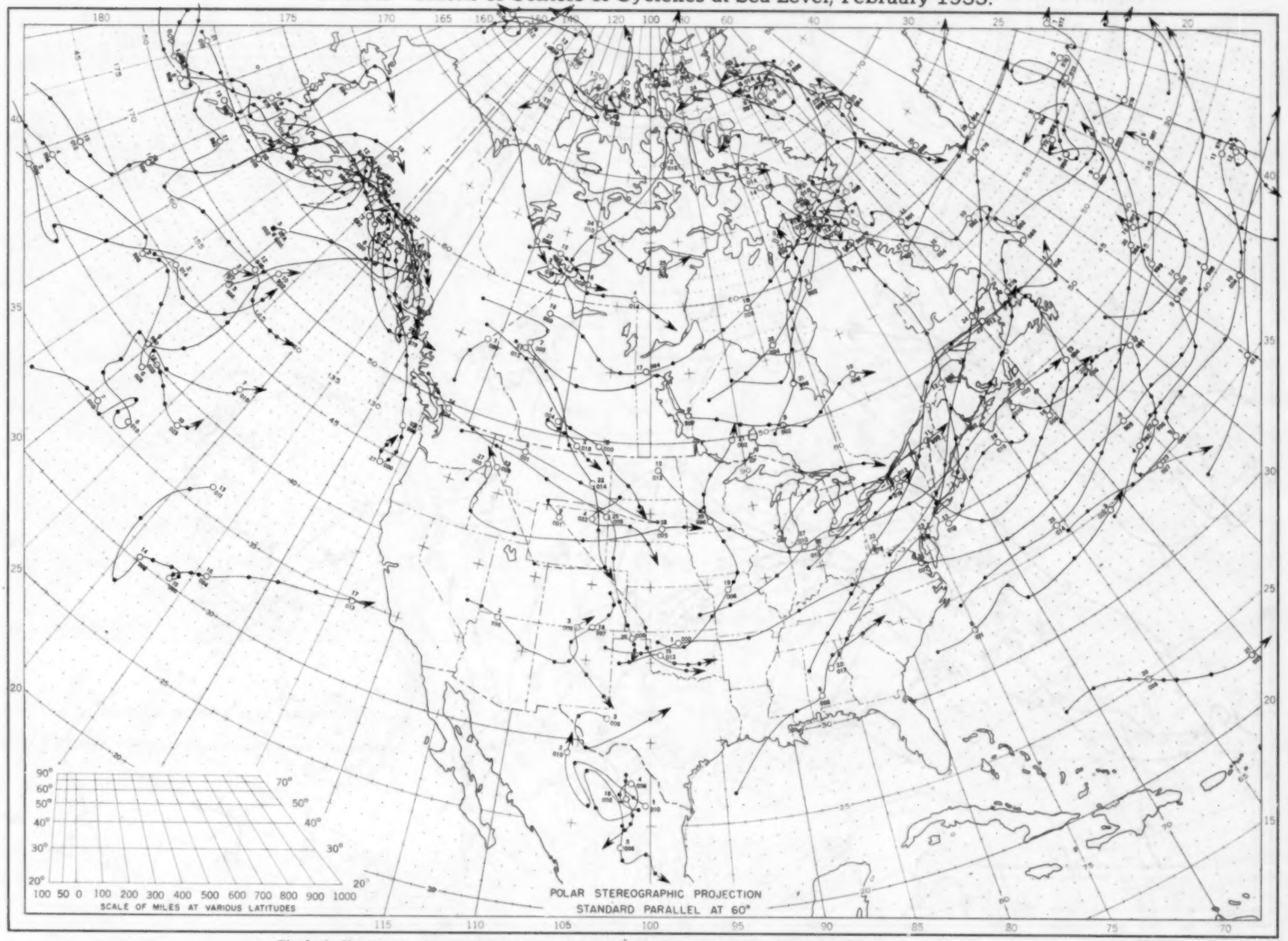
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, February 1955.


SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000
POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

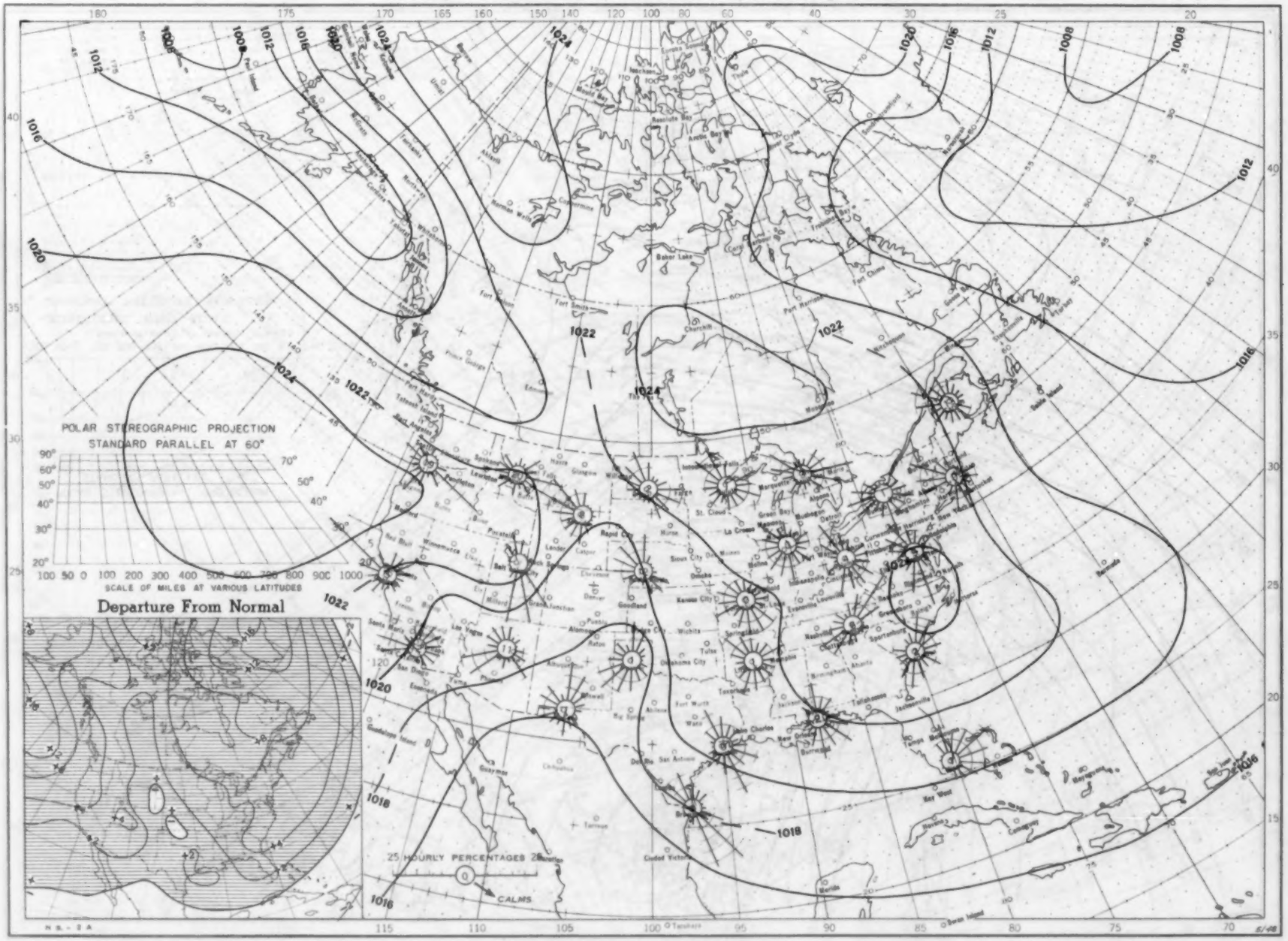
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, February 1955.


SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000
POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

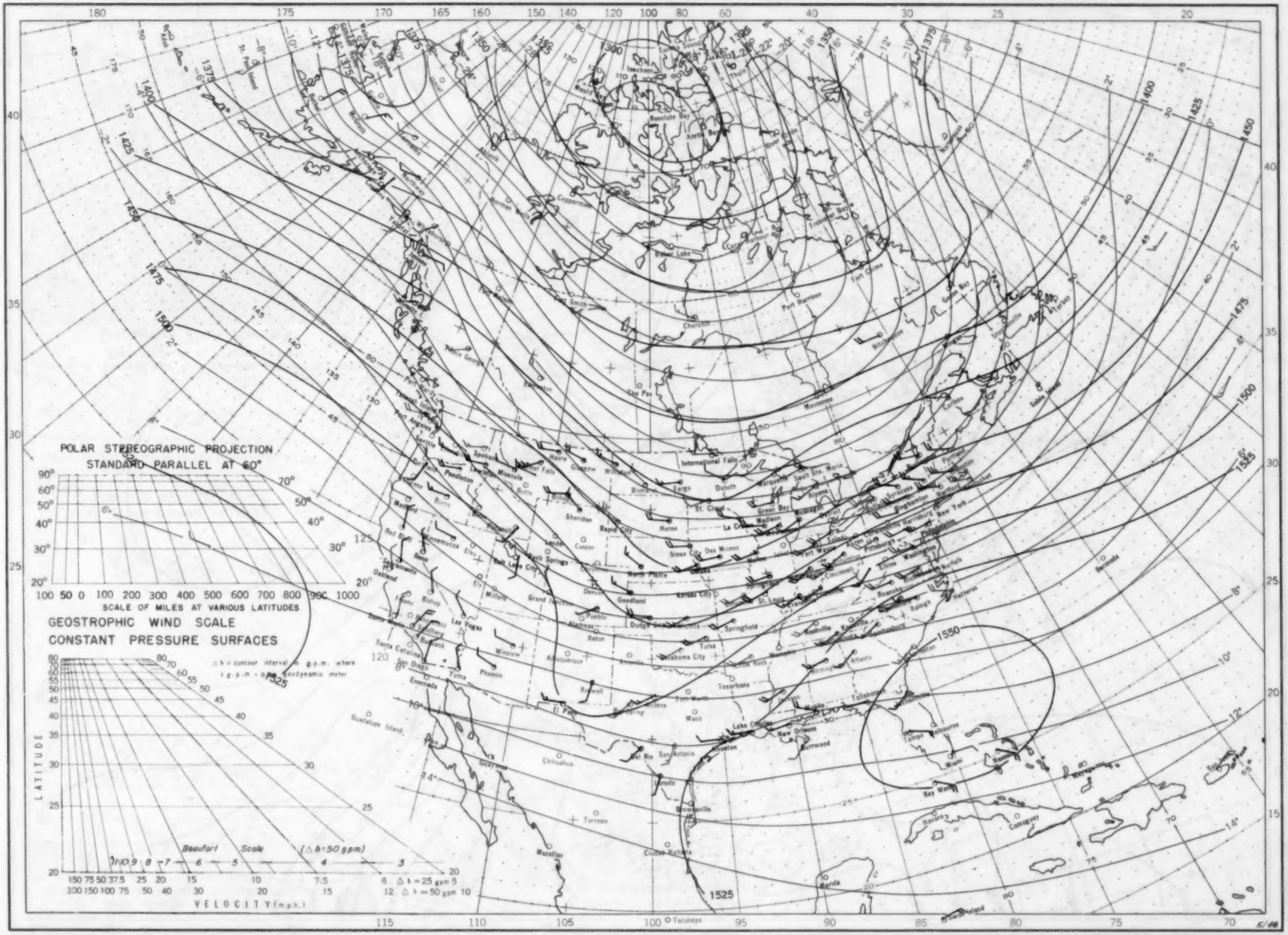
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, February 1955. Inset: Departure of Average Pressure (mb.) from Normal, February 1955.



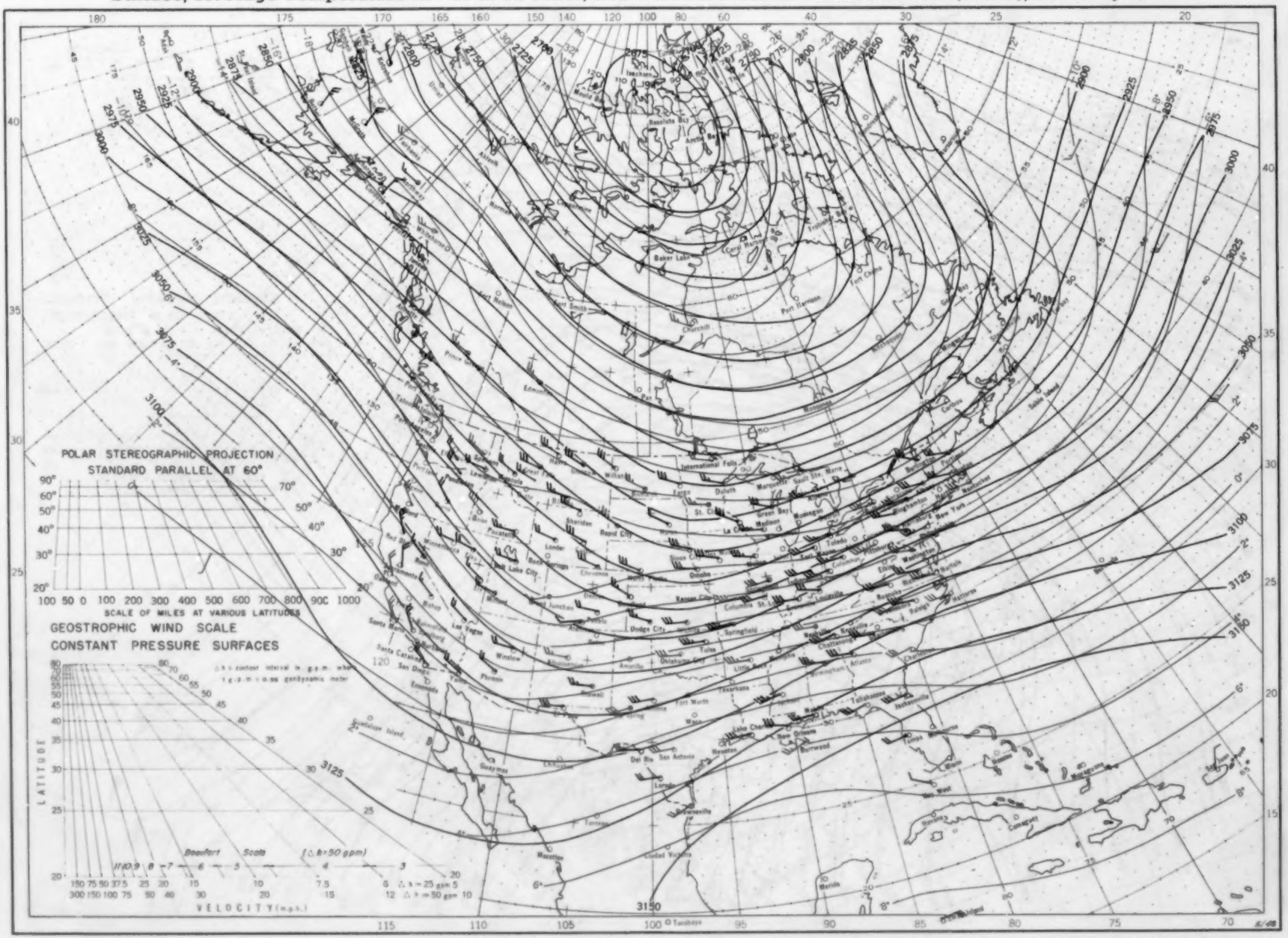
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), February 1955.



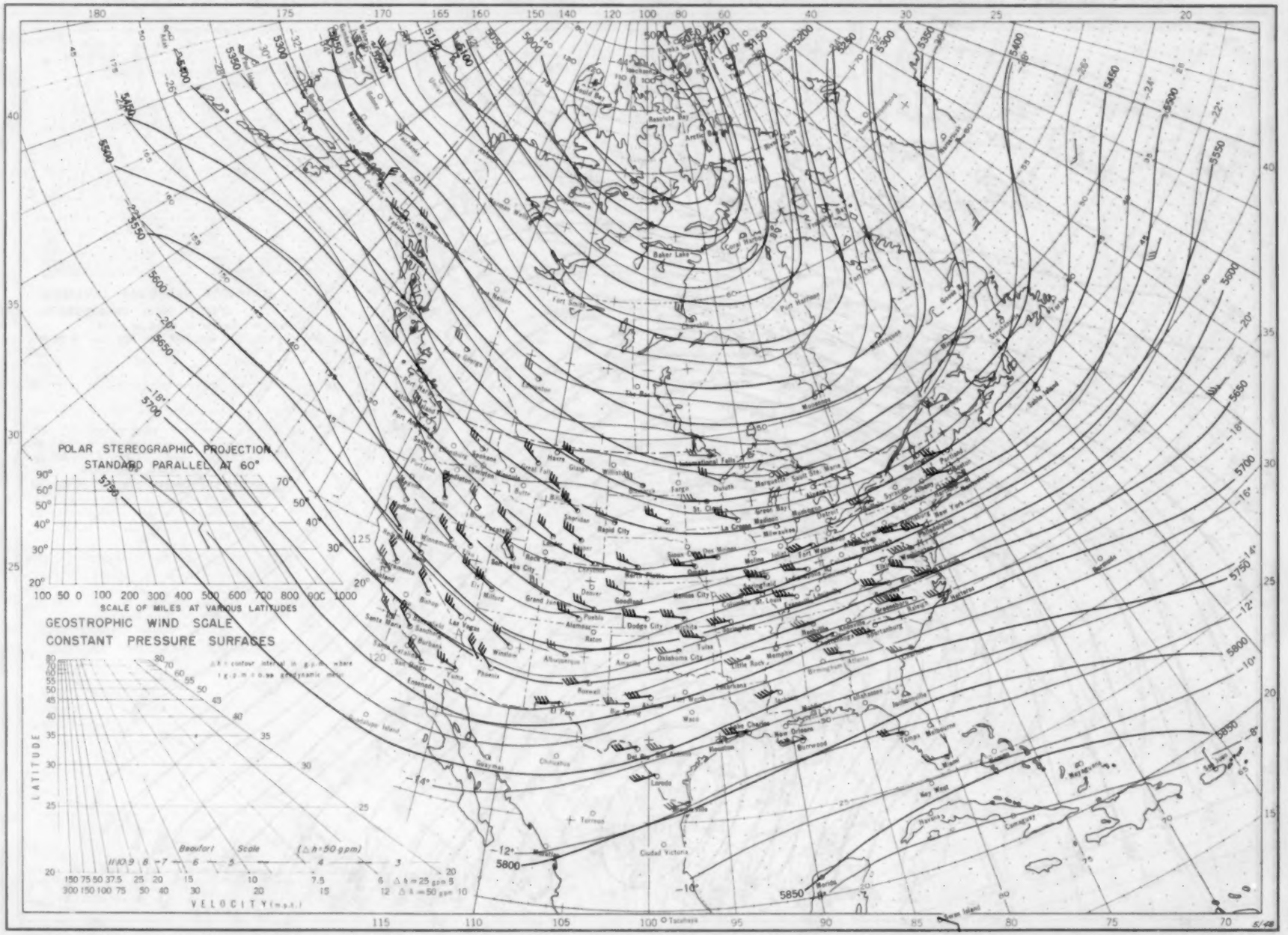
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), February 1955.



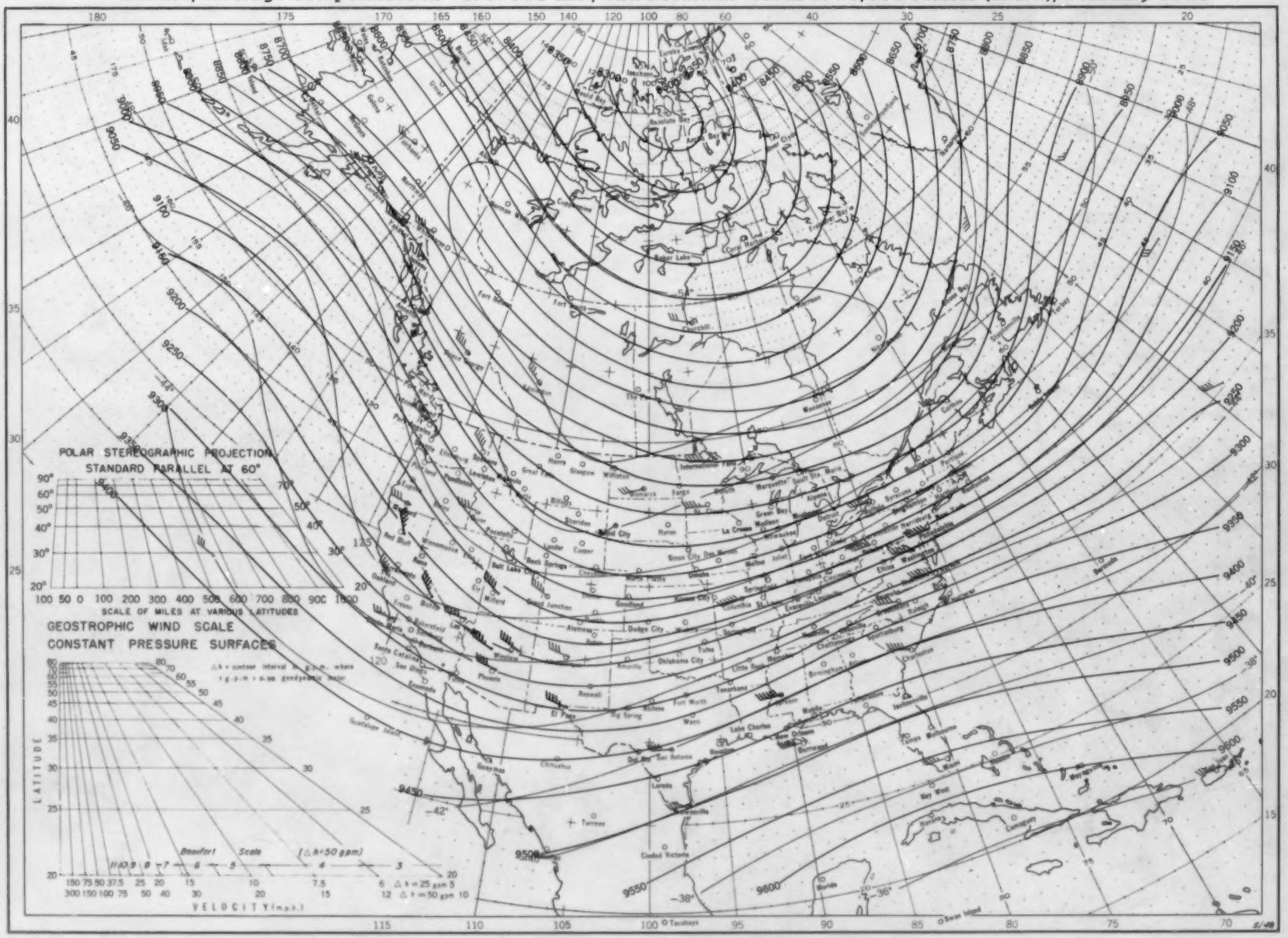
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), February 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), February 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. those shown in red are based on rawins at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; Wind barbs indicate wind speed on the Beaufort scale.